MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

LEXINGTON MASSACHUSETTS

ABSTRACT

This report contains radar cross-section measurements conducted on Echo I (60 Iota 1), a passive communications satellite, from the first revolution on 12 August 1960 to revolution 5159 on 6 October 1961. Tracks on the early revolutions, up to about 92, generally displayed a fairly constant amplitude, indicating little deformation of the spherical shape of the balloon. The smoothest observations noted had approximately ± 0.5 db (peak-to-peak) fading variations over the duration of track. Later recordings show amplitude patterns with various amounts and rates of fading. Fast scintillations, with a period of the order of 0.5 - 1 second, can be seen during certain runs as well as slow long-term fading during others.

Beginning with about revolution 1944 (18 January 1961), a gradual deterioration in the shape of the balloon was indicated by frequent deep fades and a generally rough amplitude pattern. Fades of ± 4 db can be seen throughout most of these runs, with the most severe fades (>20 db in depth) occurring during revolution 5159, the last covered in this report.

The average cross sections measured were comparable to the theoretical value of about 750 square meters, with the average becoming somewhat less during the later revolutions when fluctuations were more pronounced.

Amplitude records for fourteen of the observed passes are included. A summary is also included for a voice communications experiment conducted between Millstone and the Prince Albert Radar Laboratory during revolution 12.

Radar Cross-Section Observations
Of The Echo I Communications Satellite
at 440 Mc/s

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INTRODUCTION

Since the launch of the Echo I communications satellite much interest has been expressed in the degree to which the 100-foot diameter balloon maintained its spherical shape. Several questions have been raised as to the possible distortion of its shape in a space environment. Of chief concern is the puncturing of the thin skin by micrometeorites and the effect of thermal shock upon entering the earth's shadow. Some insight into the amount of distortion can be obtained by observing the fading characteristics of reflected radar signals. This report presents amplitude data recorded on a number of revolutions during its first fourteen months in orbit.

RADAR PARAMETERS

Pertinent parameters of the Millstone Hill Radar during these observations were as shown in Table I.

TABLE I

Frequency: 440 Mcs
Antenna: 84-ft paraboloid, 35-db tracking gain
Peak transmitted power: 1.25 to 2.5 megawatts
Pulse repetition frequency: 28 or 30 pps
Pulse length: 2 milliseconds
Transmitted polarization: right circular
Received polarization: left circular
Conical scan rate: 7.5 rev/sec (approx.)
Receiver noise figure: 2 db (approx.)
System losses: 2 db (approx.)

DATA RECORDING

For recording purposes the IF signal was range-gated and passed through a logarithmic amplifier. In the majority of cases, amplitude data were recorded on 35-mm strip film by photographing the "x"-axis of an oscilloscope to which the detected signal had been applied. The film travel speed was 14.8 inches per minute. This speed allows sufficient space on the film for sequential pulses to be distinguished. The horizontal lines appearing on the film are range marks but can also be used as grid lines in estimating relative signal strengths from the calibration.

Several runs also appear on a pen-recorded strip chart. In these cases the digital output of an amplitude sampler was reconstituted as an analog signal for recording.

Averaged target position and doppler data print-outs were obtained from a real-time digital computer which is part of the Millstone Radar system.

RESULTS

In all, nearly 100 revolutions of Echo I were tracked by the Millstone Radar from revolution 01 (12 August 1960) through revolution 5159 (6 October 1961). In many cases the satellite was tracked from horizon to horizon. Amplitude data were recorded on about 35 of these.

The passes for which amplitudes are available are listed in Table II, along with the average cross sections and fading characteristics. The average cross sections given were calculated by averaging several representative regions throughout the run. The values listed in Table II should be accurate to within $\pm$ 2 db. Amplitude recordings of a selected number of runs appear in Figs. 1 through 14. Cross-section samples at various points during each run are shown directly on the recordings.

TABLE II

Rev. No.	Date	Minutes of Data	Average Cross* Section (sq.meters)	Fading db. (pk-pk)	
01	12 Aug 60	15	850	± 1	
09	12 "	19	1050	± 1.5	irregular short and long term
11	13 "	19	845	± 0.5	slight
45	15 "	19	1080	± 0.5	slight
81	18 "	16	895	± 1	longer term
92	19 "	16	890	± 1.0	slow long term
140	23 "	11	-	± 2	irregular longer term
156	24 "	20	-	± 1.5	short term, approx. one second
166	25 "	19	-	± 1.5	short term, 0.5-2 sec.
167	25 "	19	-	± 3	0.5-1 sec. lobing
179	26 "	6	-	± 3	irregular long term
213	29 "	19	-	± 1.5	slow long term
226	30 "	17	-	± 1.5	slow long term
237	31 "	14	-	± 3	slow long term
249	1 Sept 60	20	-	± 2	slow long term
431	16 "	19	≈1000	± 2.5	slow long term
495	21 "	16	945	± 2	short and long term
636	3 Oct 60	19	725	± 3	slow long term
941	28 "	19	890	± 2	short term 1-2 sec. and long term
942	28 "	16	950	± 2	fast irregular and slow long term
1448	8 Dec 60	19	-	± 1.5	slow
1788	5 Jan 61	8	910	± 1.5	slow
1861	11 "	9	-	± 1.5	slow
1862	11 "	15	920	± 1.5	slow
1944	18 "	19	800	± 3	irregular

(Cont'd)

* The theoretical radar cross section is approximately 750 square meters.

TABLE II (Cont'd)

Rev. No.	Date	Minutes of Data	Average Cross Section* (sq.meters)	Fading db. (pk-pk)	
2042	26 Jan 61	19	-	± 4	irregular
2114	31 "	17	-	± 3	irregular
2115	31 "	12	-	± 4	irregular
3147	25 Apr 61	10	625	± 3	irregular
3404	16 May 61	3	-	± 3	irregular
3941	29 Jun 61	19	620	± 5	irregular
4268	25 Jul 61	11	≈ 700	± 3	irregular
				(with fades 8-10 db in depth)	
5148	5 Oct 61	17	-	± 4	irregular
				(with fades >10 db in depth)	
5159	6 "	16	≈ 700	± 4	irregular, deep fades
				(with fades >20 in depth)	

* The theoretical radar cross section is approximately 750 square meters.

Of more interest perhaps than the average cross-section measurements are the fading characteristics which are indicative of the balloon deformation. Early revolutions recorded, up to number 92, displayed smooth amplitude patterns with signal variations of the order of ± 1 db. Right-circular polarization was transmitted and left-circular recorded. A spot check from time to time, during these early passes, of the relative signal strength of the two orthogonal received polarizations indicated a ratio of about 20 db. The small magnitude of the depolarized component indicated that the balloon had fully inflated and maintained its sphericity to a high degree during this time (and, incidentally, also served as a check on the circularity of the transmitted signal). Figures 1 through 4 (revolutions 01, 09, 11 and 45) are representative amplitude recordings of this early group of passes.

During revolution 01 rapid scintillations, at a rate of 3 or 4 per second, can be seen at 06h 57m 10s and may arise from interference with the final stage of the launching rocket which probably was still within the radar beam at this time. This effect can be seen to a certain extent at other times during the run. Occasionally a regular variation is seen every four pulses. This variation is due to the conical-scan modulation of the radar and is most apparent at time of acquisition.

Revolution 09 displayed the most fading (± 1.5 db) of the early passes and also appears to contain reflected ray interference, with signal enhancement and cancellation, near the horizon. This is noticeable near the beginning and end of track. It is also evident to a degree during other runs.

Revolution 11 contains the smoothest amplitude record made. It was tracked for about 19 minutes with fading of only ± 0.5 db.

Following revolution 92, more fading was observed (± 1.5 - ± 3 db), with the ratio of the two orthogonal received signals at times approaching 6 db.

Fading was generally slow, occurring at irregular intervals, until revolution 156 when a periodicity of 0.5 - 1 second became apparent. It is interesting to note that revolution 156 occurred soon after the satellite first entered the earth's shadow. This rapid scintillation was last observed during revolution 167 (Fig. 5) when sharp nulls (4-5 db) were recorded. The short-term fading was not seen during nine passes tracked between revolutions 179 (Fig. 6) and 636 (Fig. 7). Instead, longer term, irregular variations of $\pm$ 1.5 - $\pm$ 3 db were observed.

During the two revolutions 941 and 942, a faster fading rate, of the order of one second, was again observed and was most pronounced during the first half of the observation of revolution 942 (Fig. 8). This short-term fading was not observed during the last half of this track but instead gave way to a slow rolling amplitude pattern. This change in fading characteristic, over the duration of a single track, suggests a relatively smoother surface for a portion of the balloon. A very pronounced ground effect can be seen again at the end of this track.

Amplitude data were not available between revolutions 942 and 1448.

Four tracks conducted between revolutions 1448 and 1862 indicate a smoother target with a longer fading interval and somewhat shallower depth ($\pm$ 1.5 db). No short-term scintillations were observed during this time. Figure 9 (revolution 1862) is typical of these runs.

On ten tracks taken between revolutions 1944 and 5159, a gradual deterioration of the balloon was indicated by occasional very deep fades and a generally rough amplitude pattern. (Revolutions 1944, 3147, 3941, 4268 and 5159 appear in Figs. 10 through 14.) Fades of the order of 10 db can be seen throughout most of the runs, with the most severe fading recorded during revolution 5159, the last covered in this report. During this revolution two deep

fades (>20 db) were observed having similar characteristics and occurring 6 min 40 sec apart. The track was not long enough to determine whether the effect was repeated. The cross section at the depth of the fades was of the order of 10 square meters.

These observations are summarized in the approximate groupings shown in Table III.

In the Appendix is a summary of a UHF communications experiment conducted during revolution 12 between Millstone and the Prince Albert Radar Laboratory.

Computer print-outs of position and doppler observations are not included in this report.

CONCLUSION

The series of radar observations conducted on Echo I suggest that the balloon was fully inflated soon after launch and maintained its spherical shape to a reasonable degree until approximately the time it first entered the earth's shadow. The rapid and regular fading observed soon afterward may have resulted from interference between reflections from the individual gores making up the structure. This effect might have been accentuated by shrinking of the balloon following a loss in internal pressure, giving it a pumpkin-like appearance.

The irregular and more pronounced fading after this time suggests a further deterioration of the general shape of the balloon with, however, either a modest recovery to sphericity or a relatively smooth surface for only a portion of the balloon, in observations following this. The change in fading pattern, from rapid short-term fluctuations to smoother long-term fading, during the track of revolution 942 would suggest a slow rotation to a smoother portion of the balloon.

TABLE III

Revolutions Observed	Fading Characteristics	Comments
01, 09, 11, 45, 81, 92	Smooth, slow fading; ± 0.5 to ± 1.0 db fluctuation; revolution 09 poorest: ± 1.5 db.	Ratio of 2 received orthogonal polarizations approx. 20 db.
140, 154, 155	± 2 db irregular fading; generally longer term.	Ratio of received signals approach 6 db at times.
156, 166, 167	Rapid, regular fading; 0.5 to 1 sec. period; dips to 5 db.	
179, 213, 225, 226 237, 249, 431, 495 636	± 1.5 to ± 3 db irregular fading; generally slow 5-30 sec.	
941, 942	Short (1-sec) and longer term irregular fading ± 1 to ± 2 db.	
1448, 1788, 1861 1862	Smooth, slow fading ± 1.5 db.	
1944, 2042, 2114 2115, 3147, 3404 3941, 4268, 5148 5159	± 3 to ± 5 db irregular fading generally, occasional deep fades: 8->20 db.	Deep fades indicate severe distortion of balloon shape.

Since the geometry explored during the course of any run is limited and, in the face of an unknown rotation rate and orientation, it is difficult to say whether the changes noted in the fading pattern from run to run are characteristic of the condition of the balloon or of the geometry.

Beginning with the observation of revolution 1944, a steady degradation of the balloon is evident with, perhaps, multiple punctures taking their toll. The last revolution included in this report (number 5159, 6 October 1961) points to a grossly distorted structure.

ECHO I AMPLITUDE

Revolution 01

12 August 1960

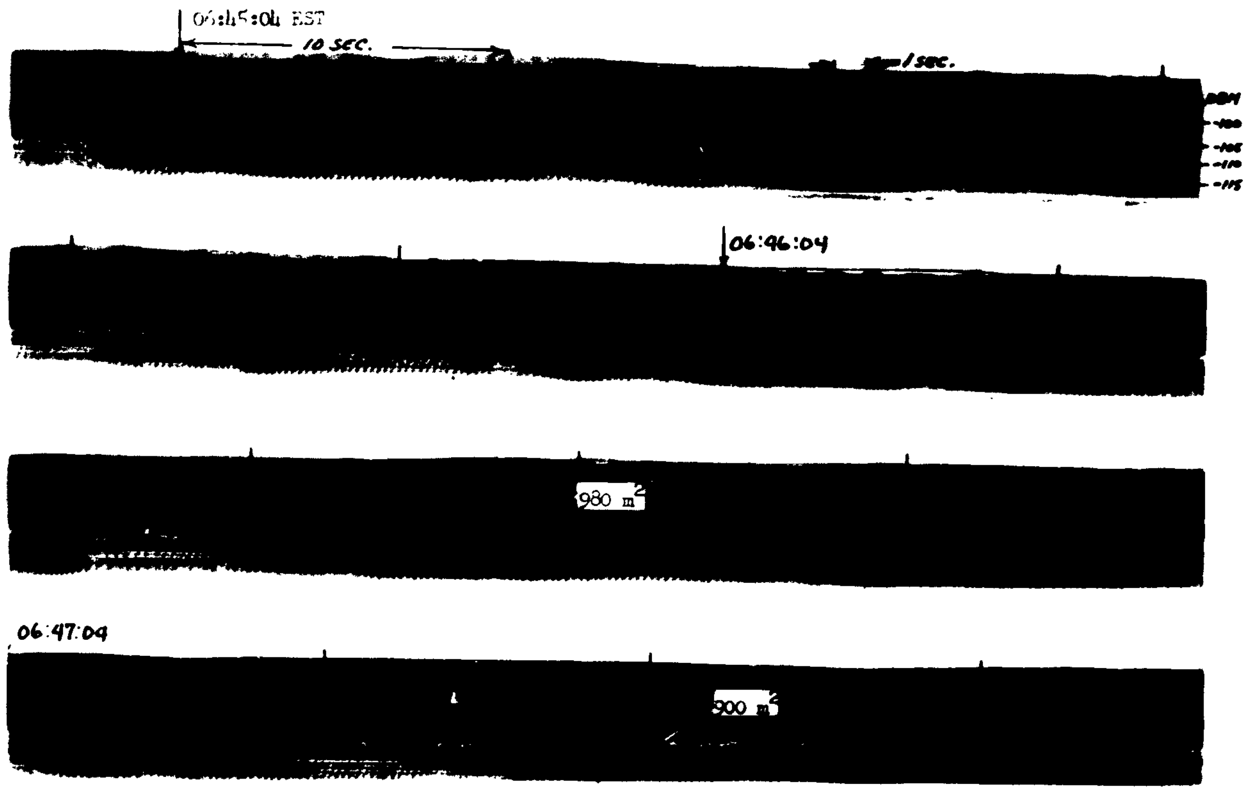


FIG. 1 PART 1

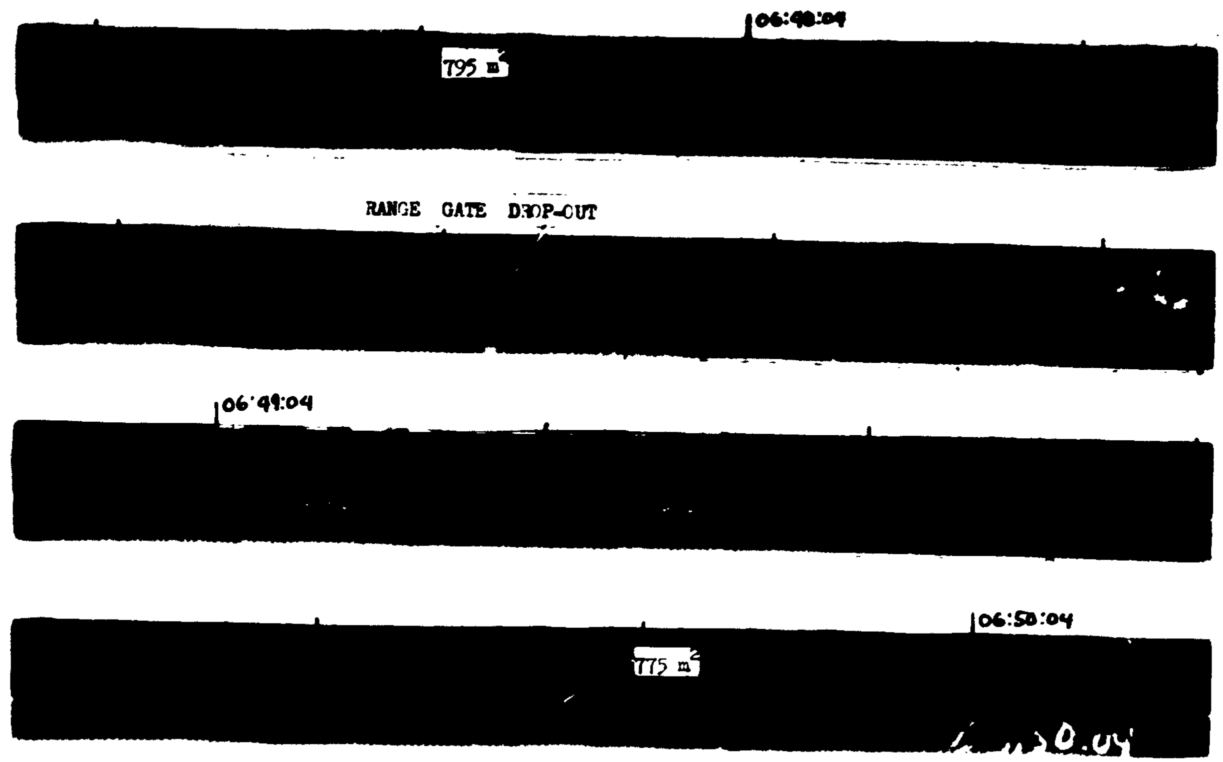


FIG. 1 PLATE 2

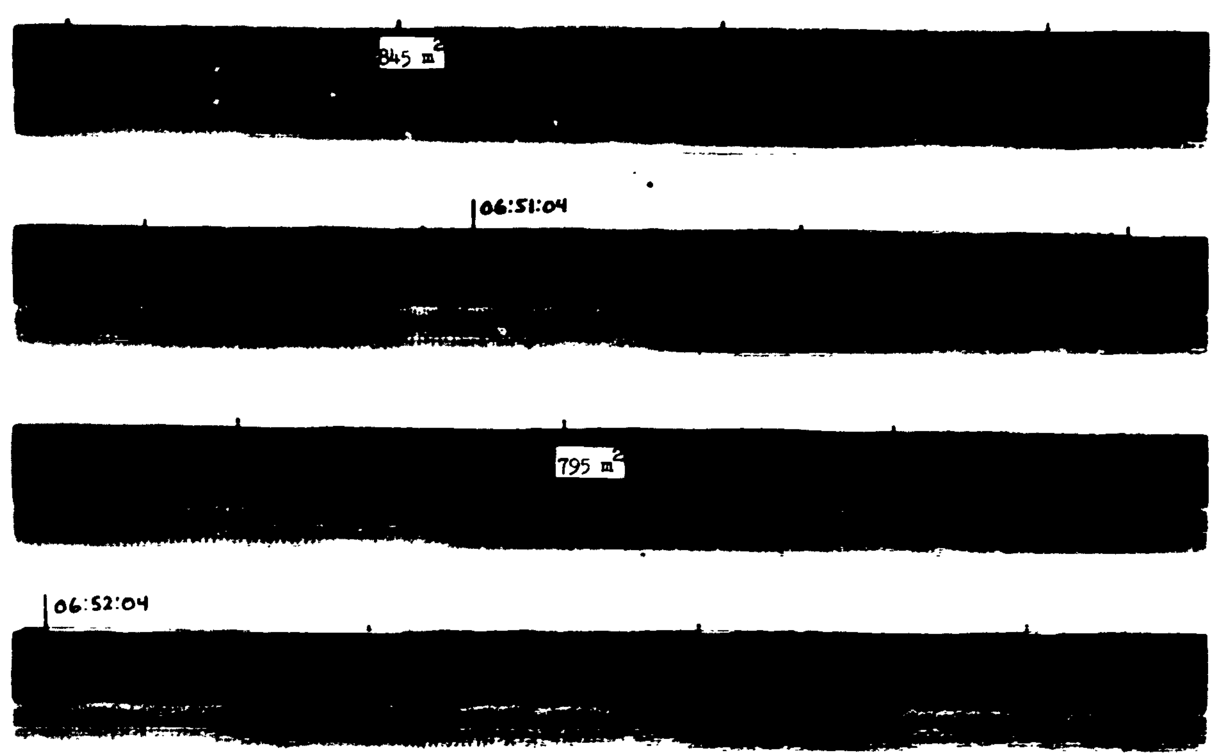


FIG. 1 FLARE 3

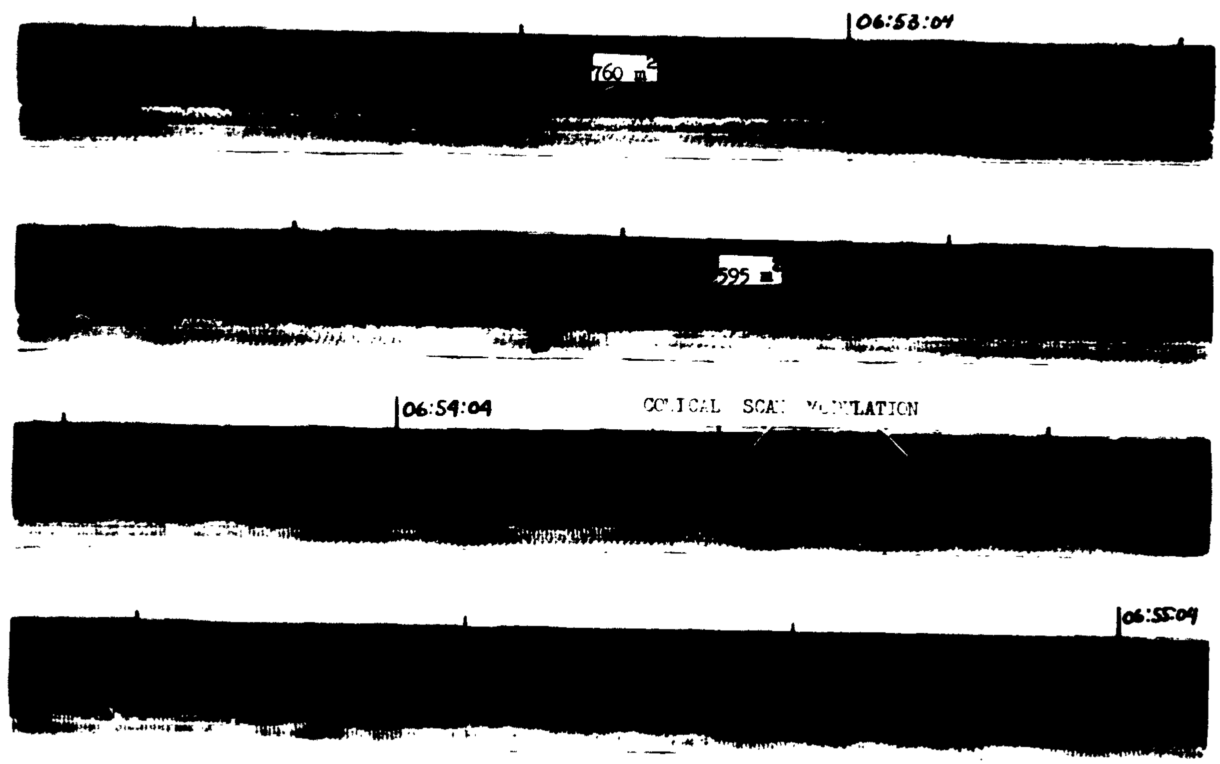


FIG. 1 PLATE 4

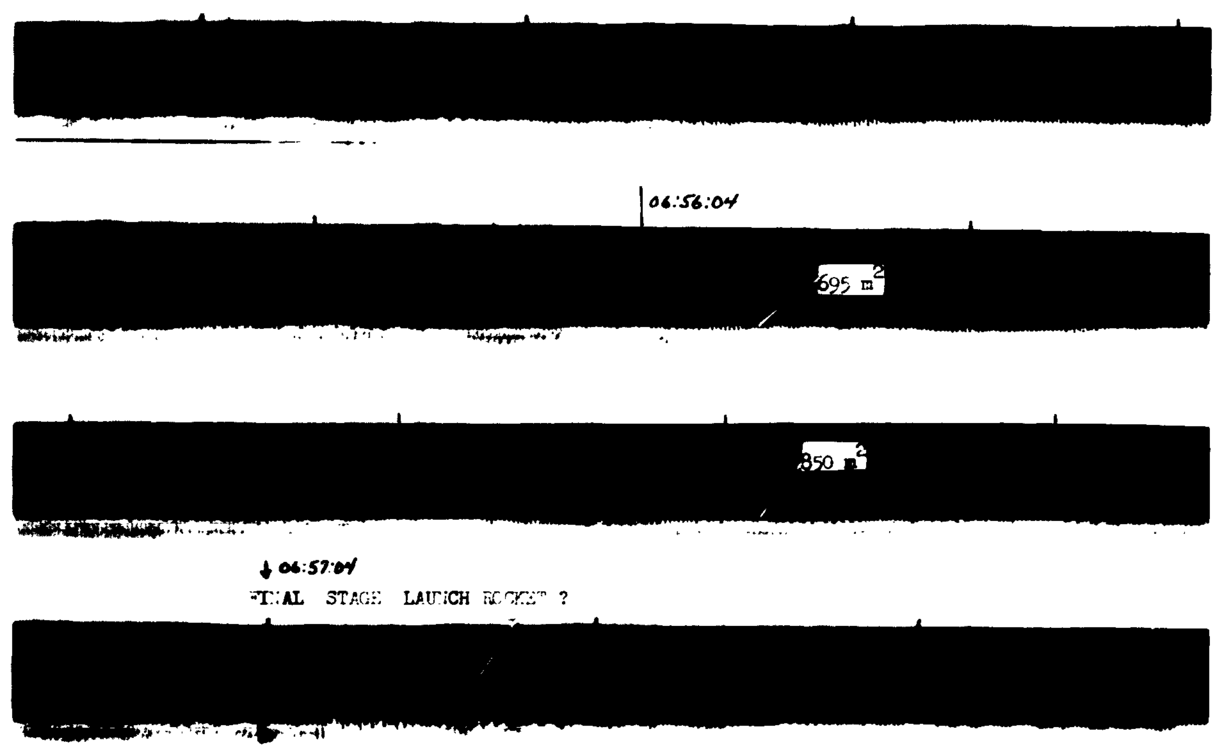


FIG. 1 PLATE 5

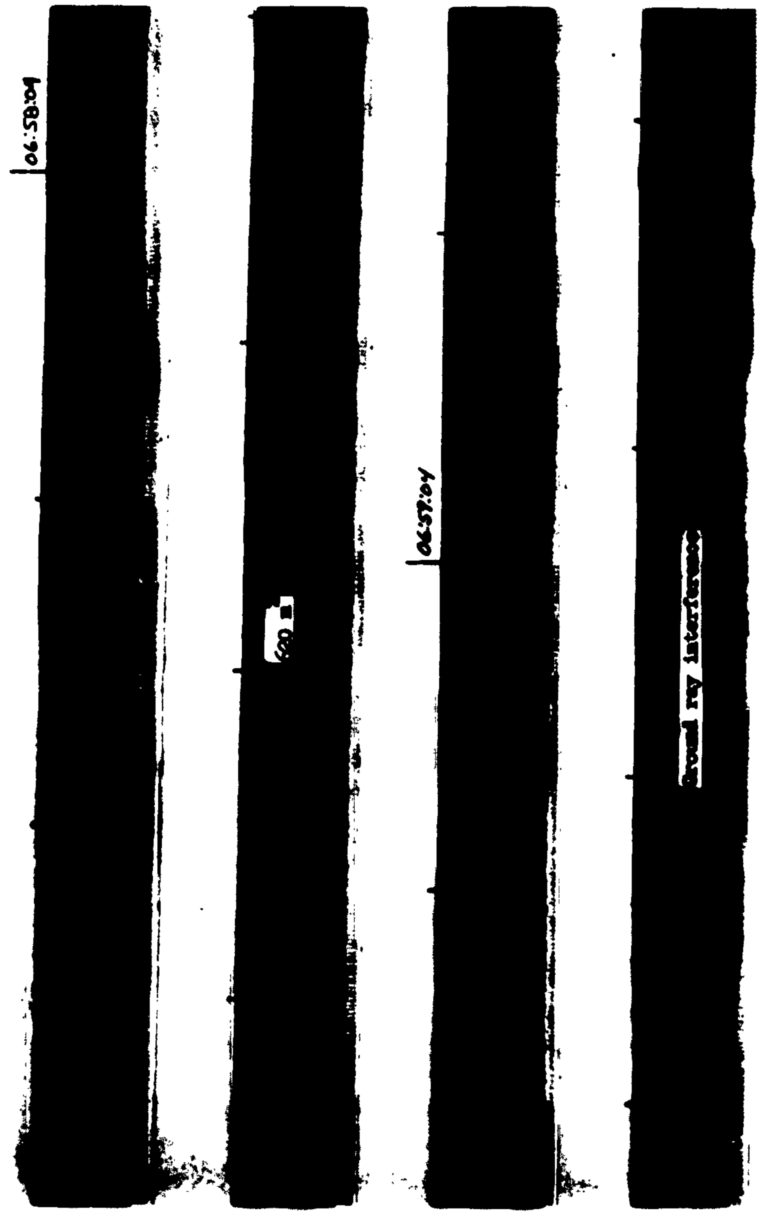


FIG. 1 PLATE 6

ECHO I AMPLITUDE

Revolution 09

12 August 1960

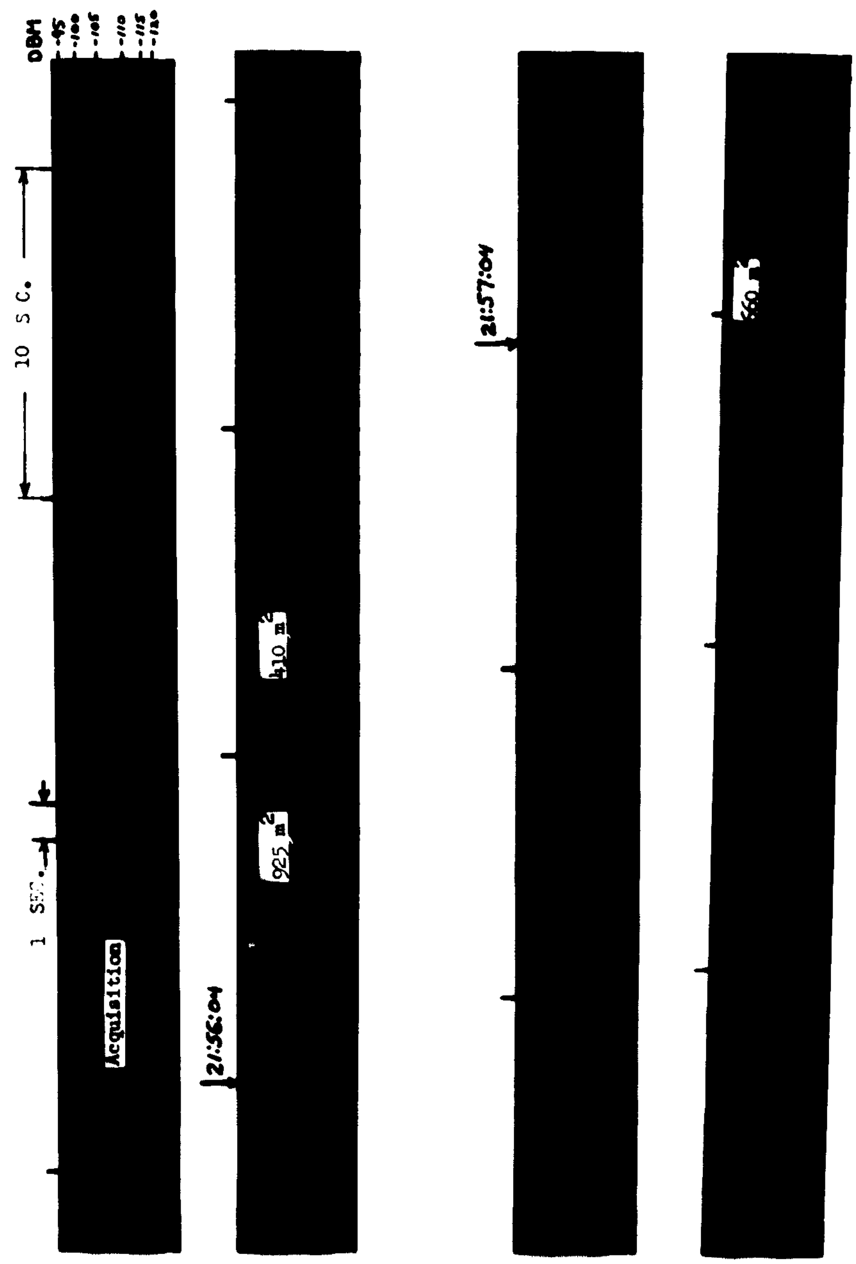

DBM
10 SEC.
1 SEC.
Acquisition
21:56:04
410 m²
925 m²
21:57:04
560 m²

FIG. 2 PLATE 1

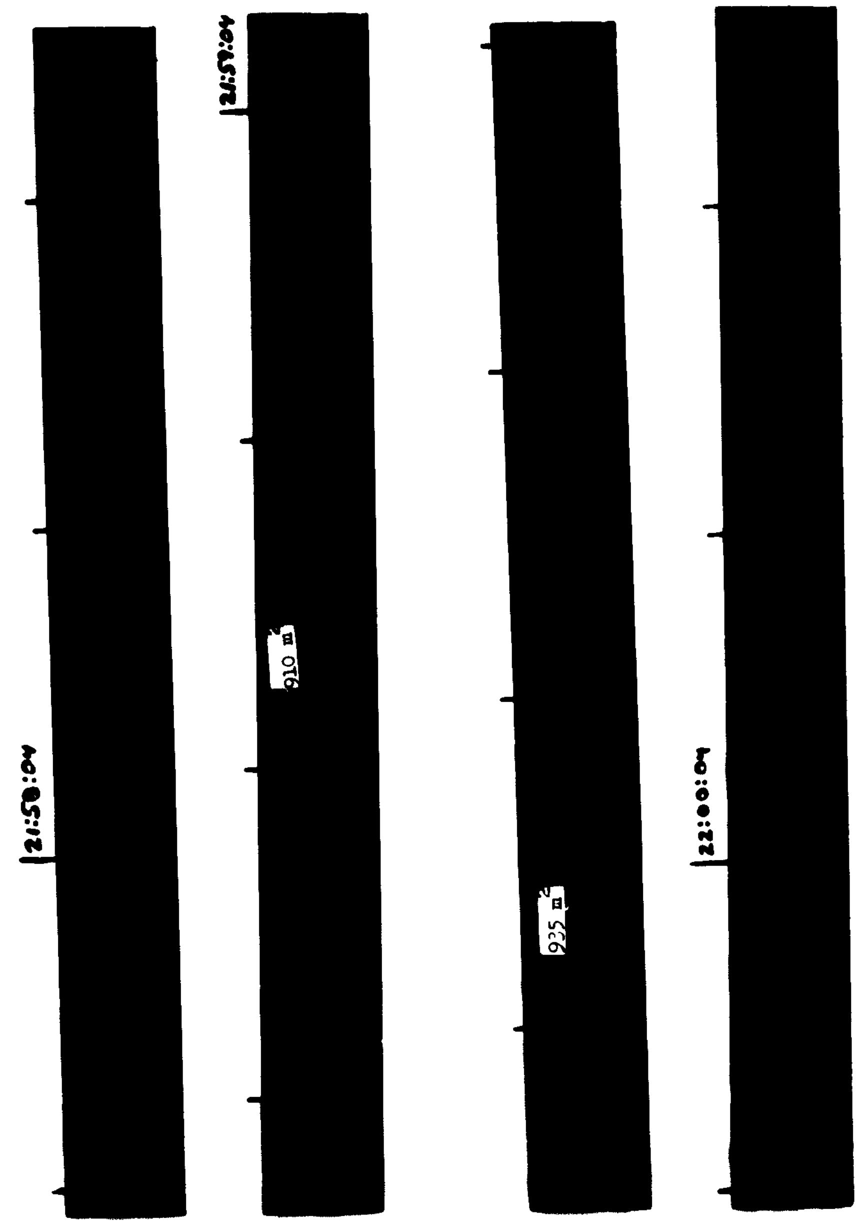


FIG. 2 PLATE 2

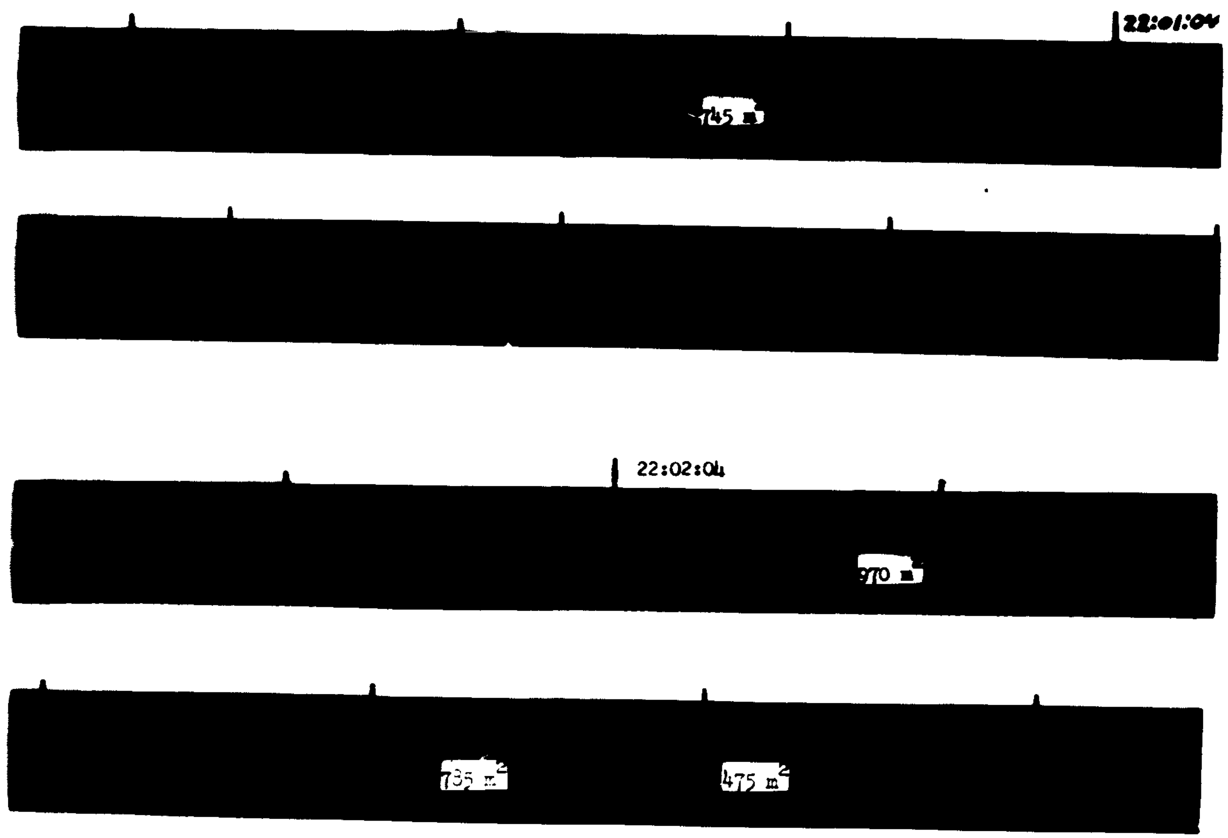


FIG. 2 [illegible] 3

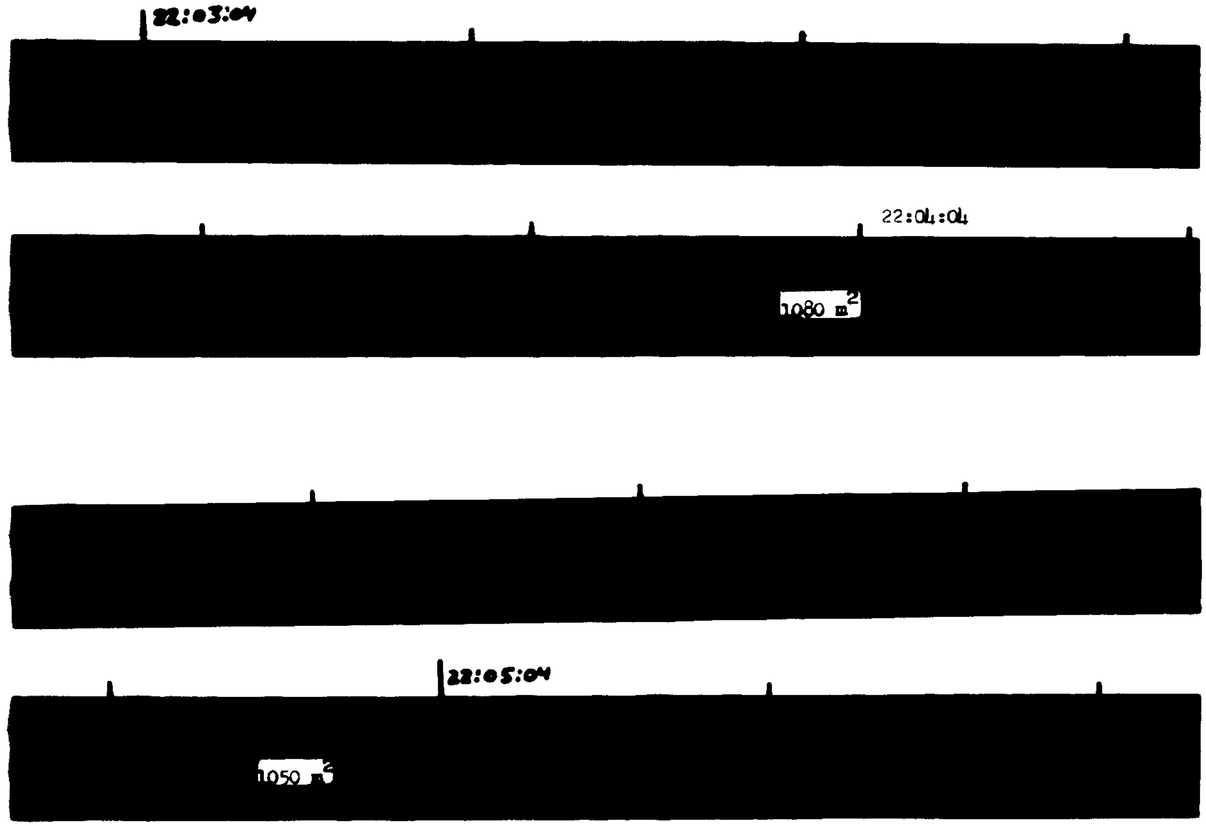
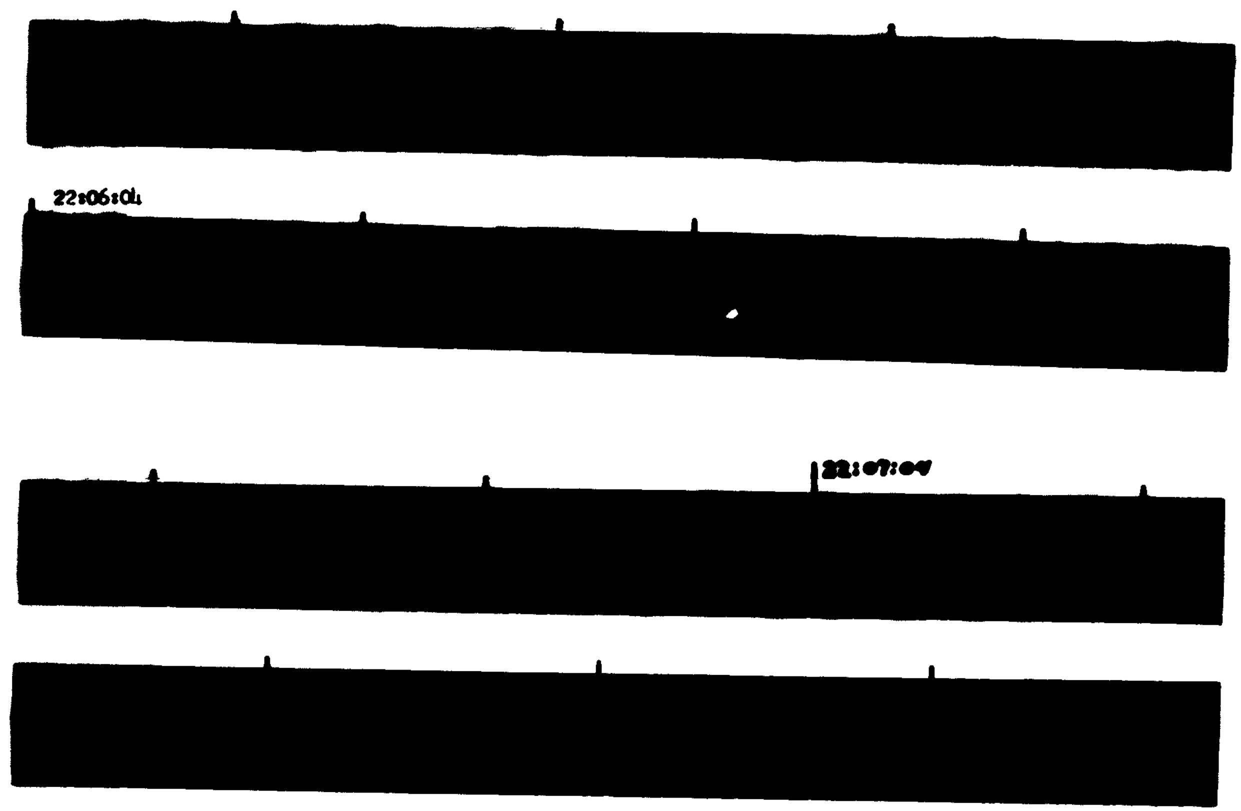


FIG. 2 PL[illegible]



F:G. 2 PLATE 5

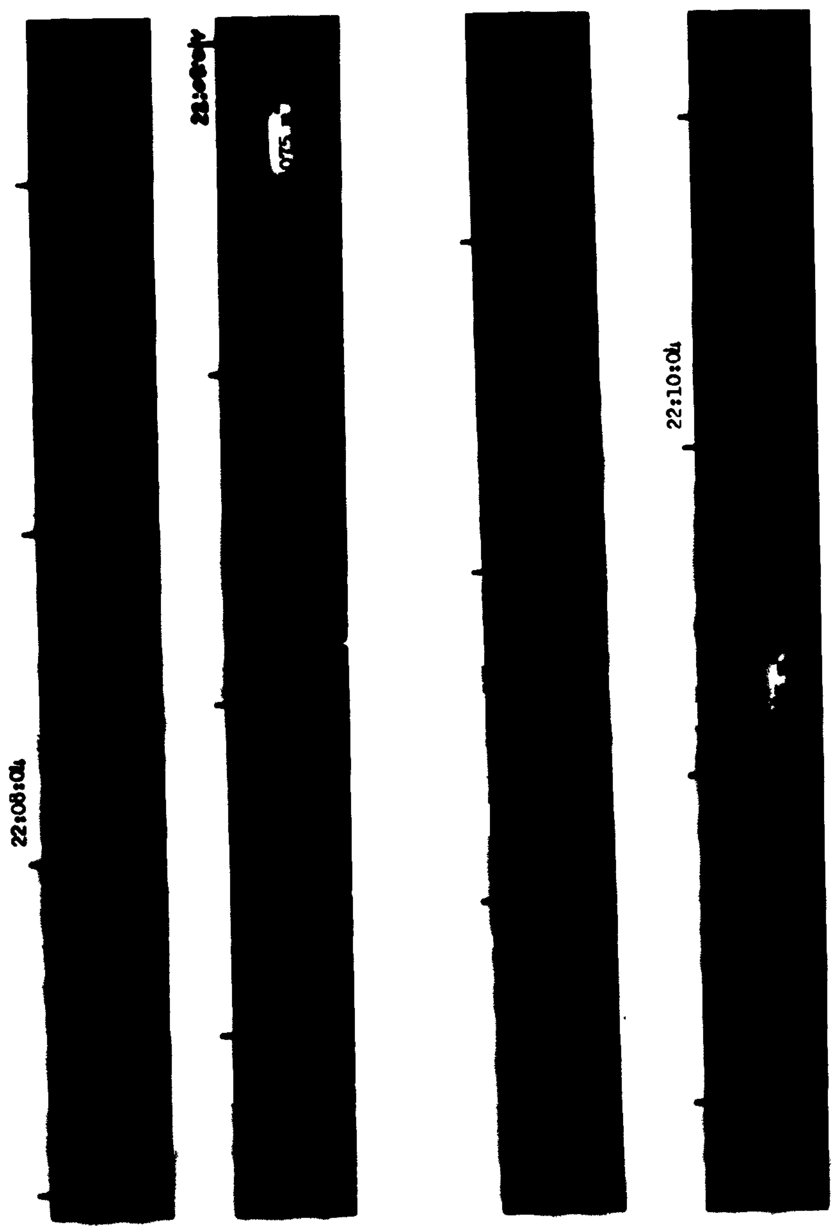


FIG. 2 PLATE 6

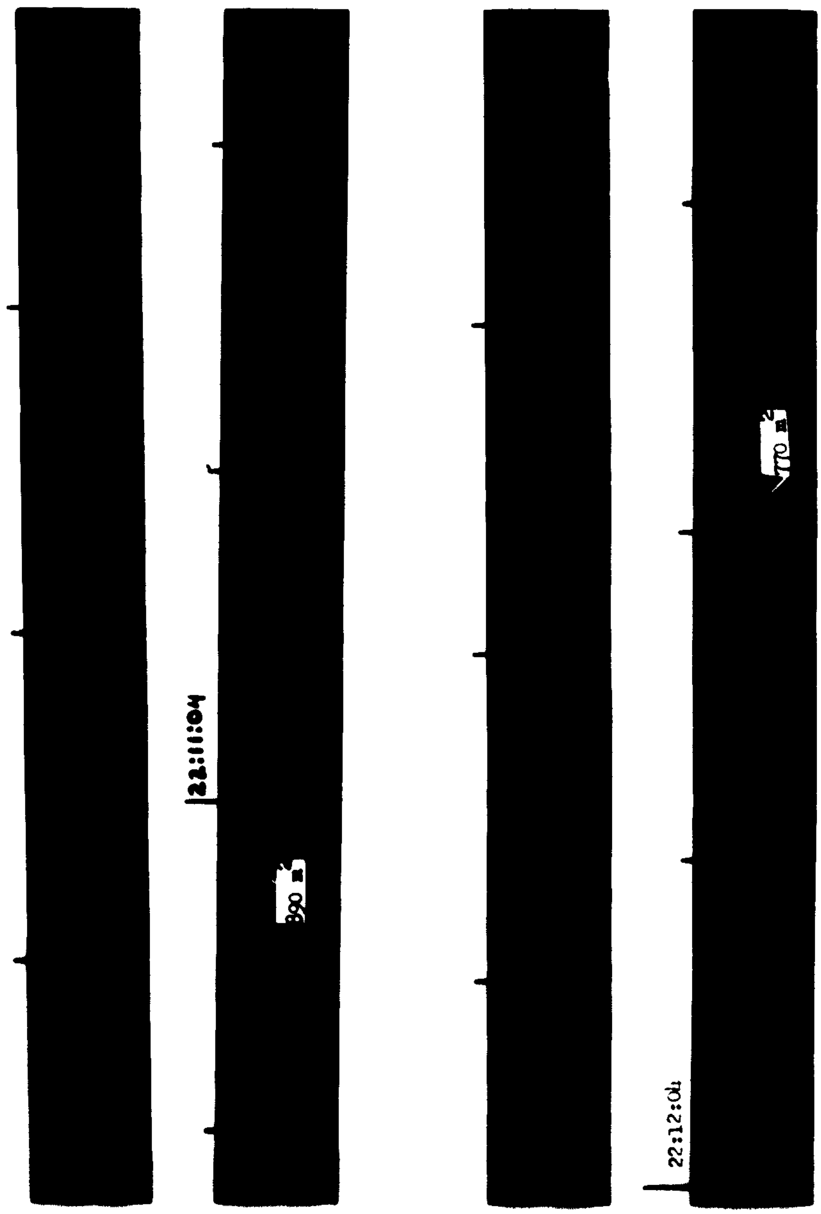


Fig. 2 [illegible]

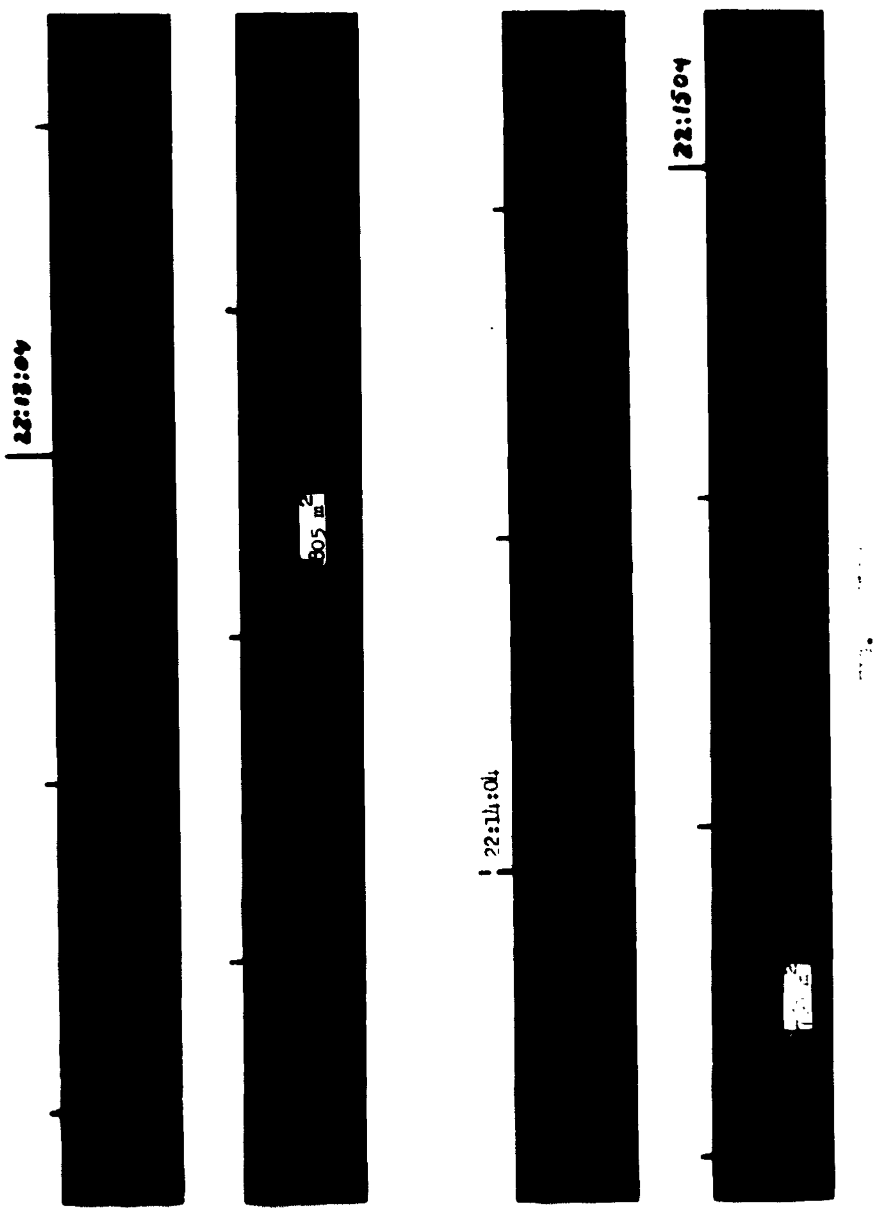

22:13:04
305 m
22:11:04
22:15:04

FIG. 2 PLATE 9

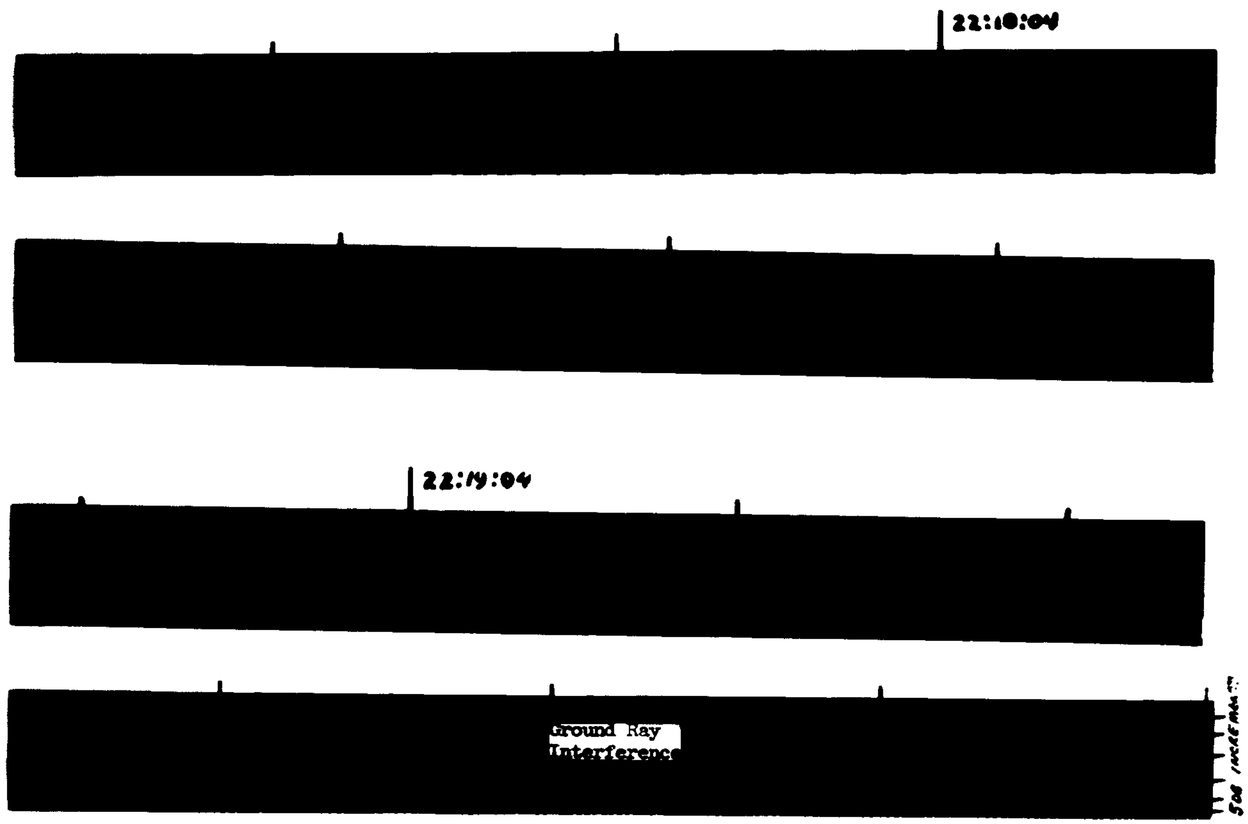


FIG. 2 PLATE 10

ECHO I AMPLITUDE

Revolution 11

13 August 1960

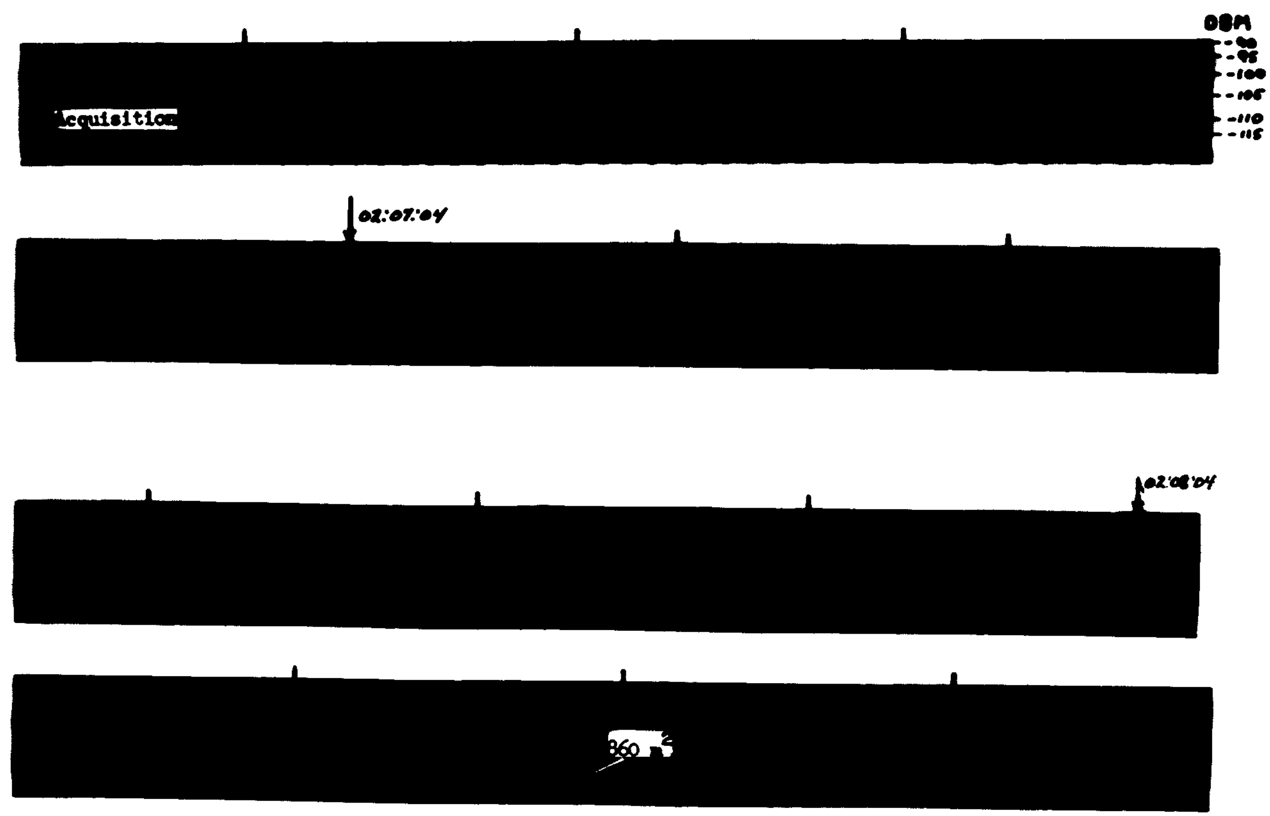


FIG. 3 PLATE 1

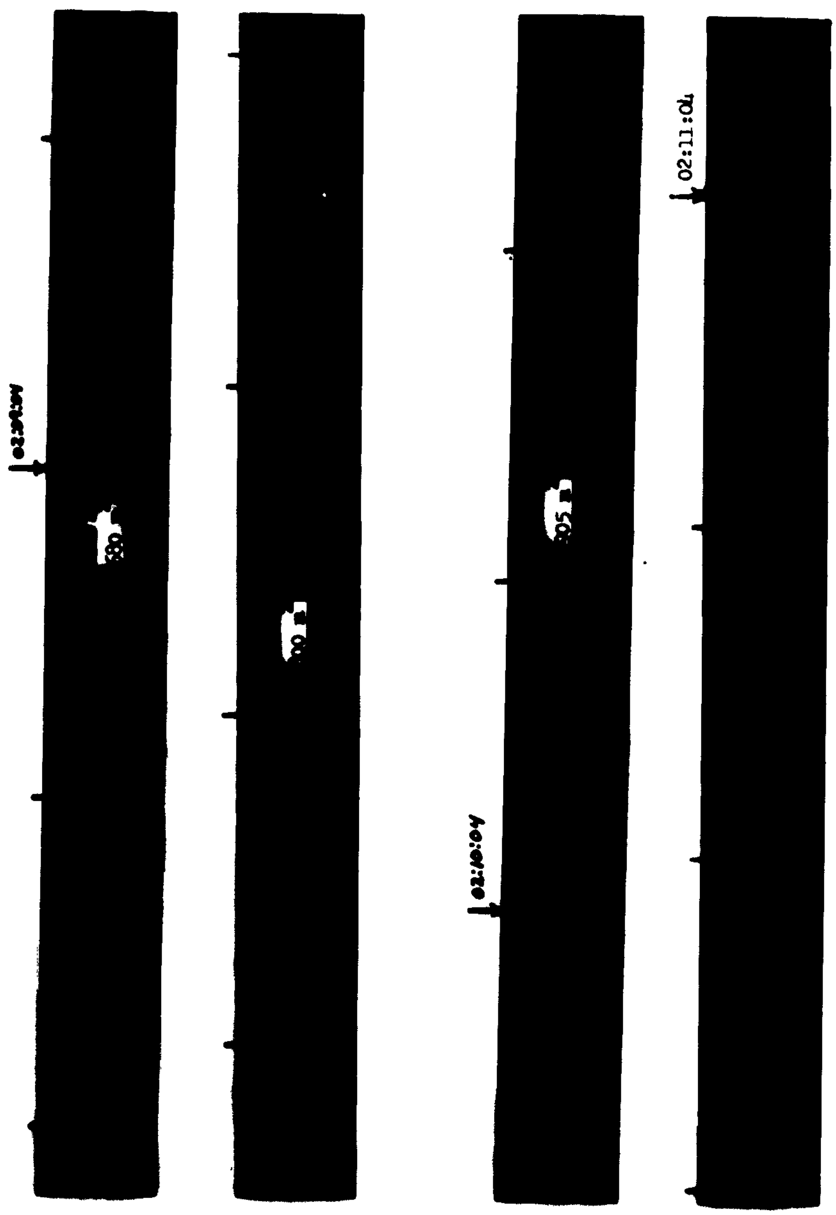


FIG. 3 PLATE 2

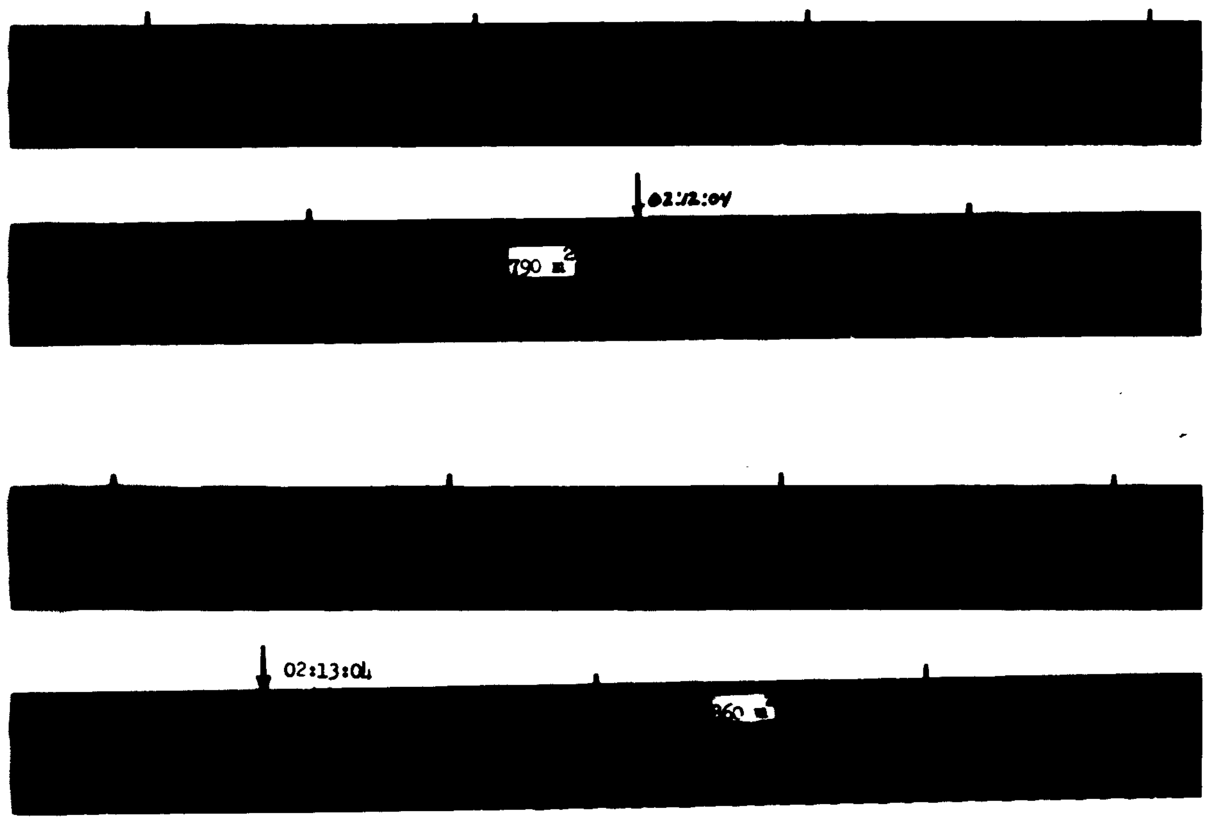


FIG. 3 PLATE 3

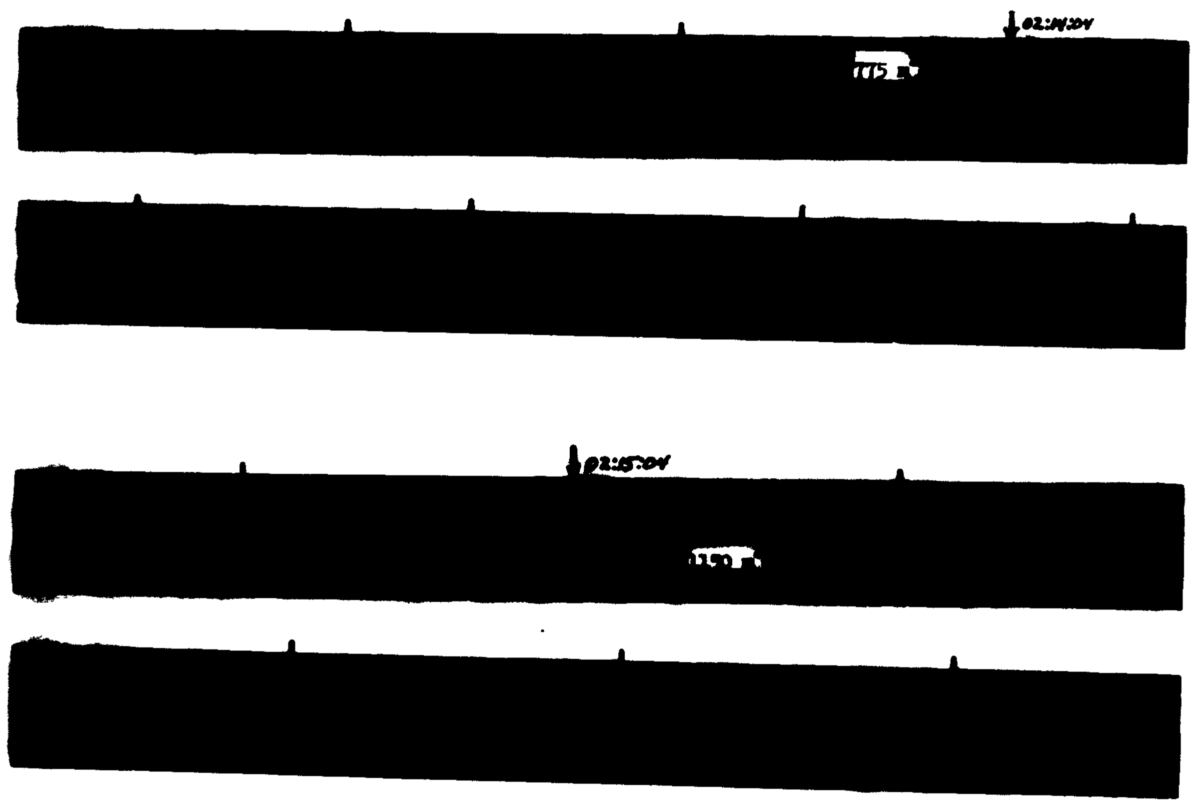


FIG. 3 PLATE 4

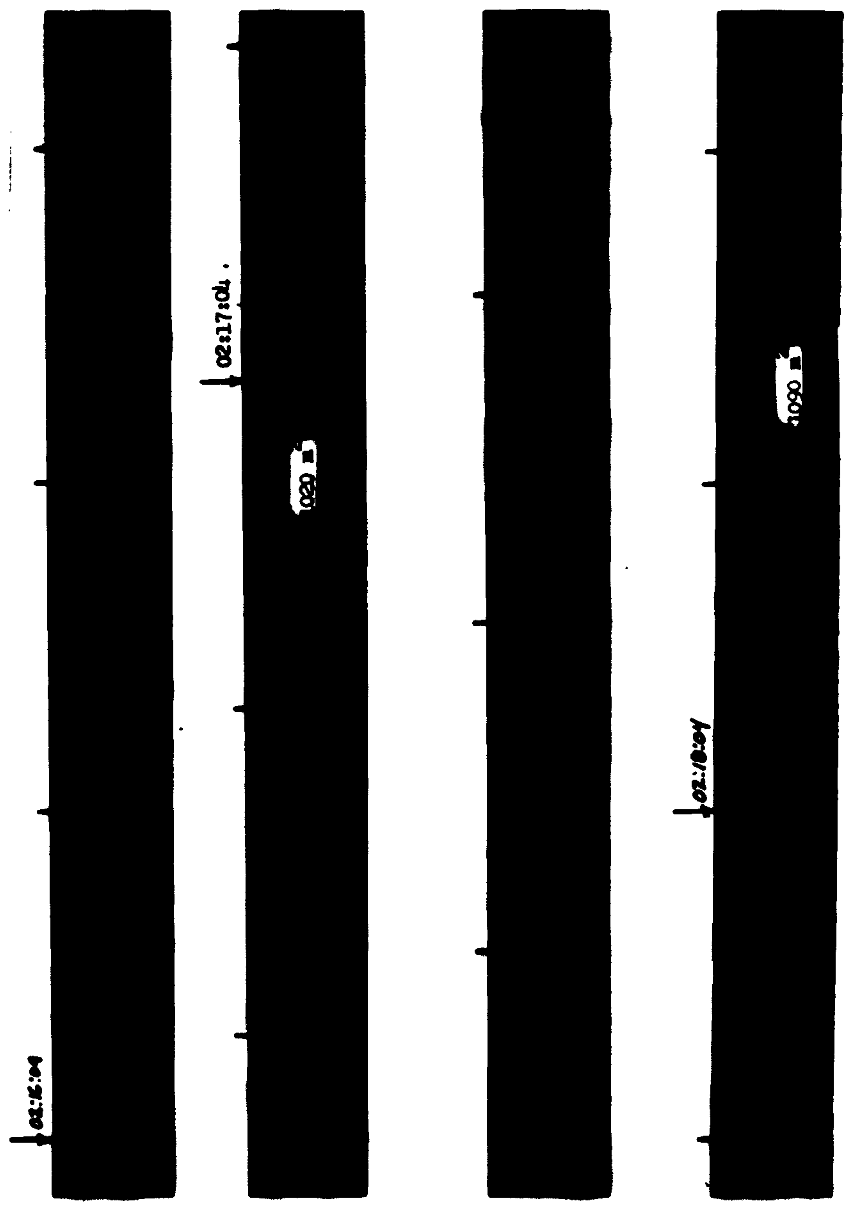


FIG. 3 PLATE 5

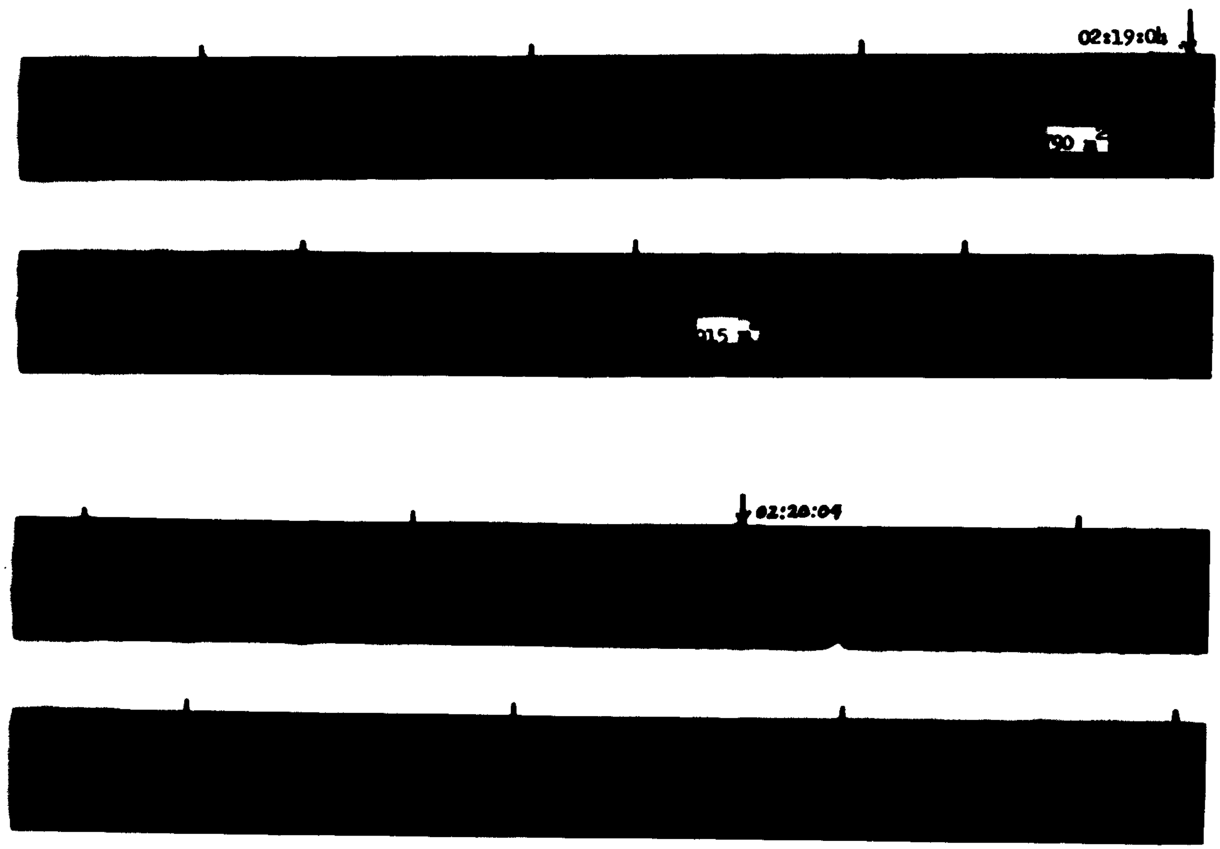


FIG. 3 PLATE 6

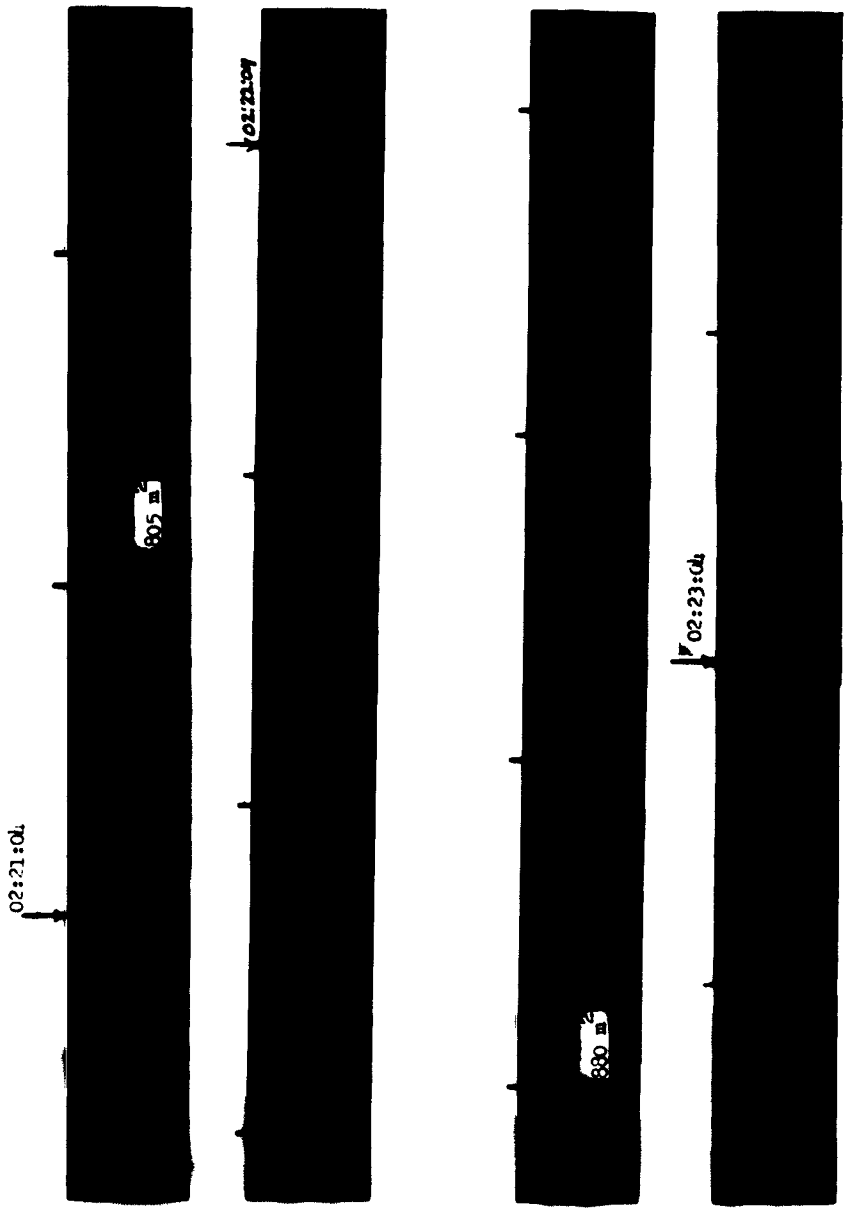


FIG. 3 PLATE 7

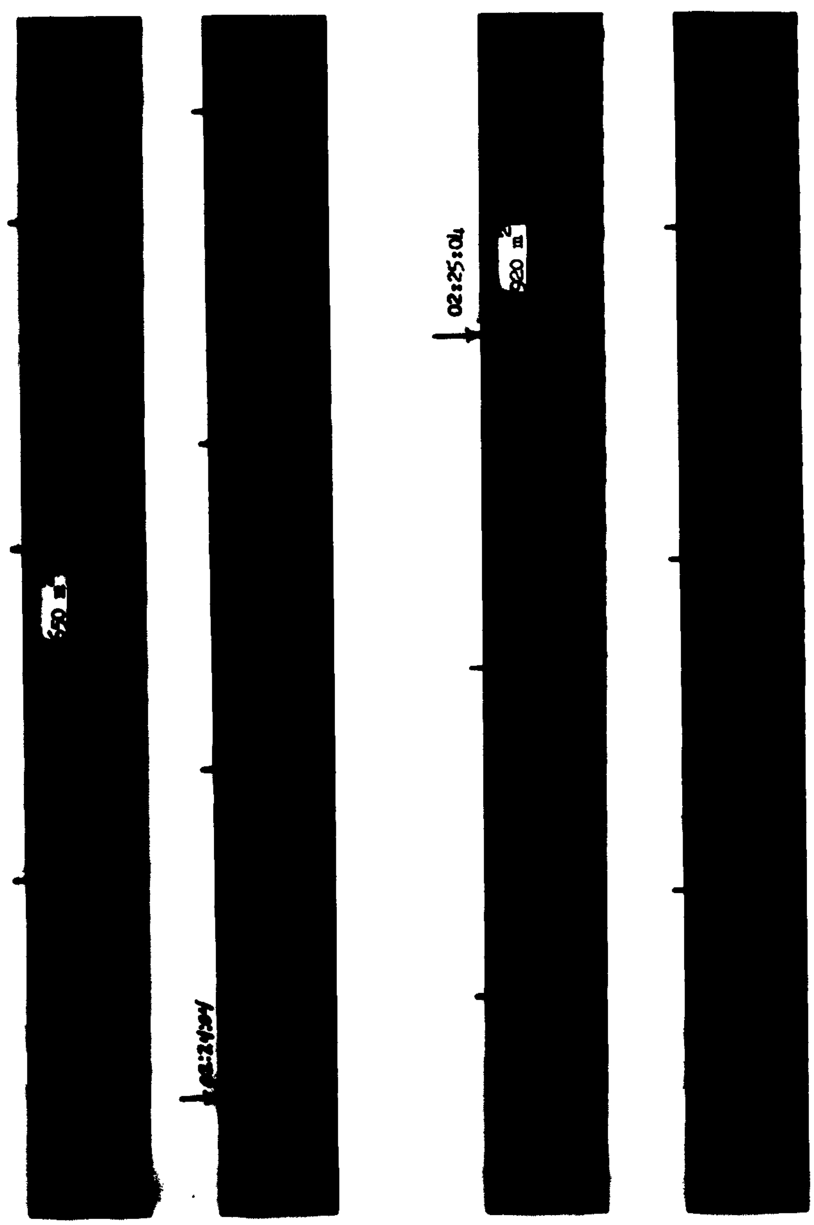


FIG. 3 PLATE 8

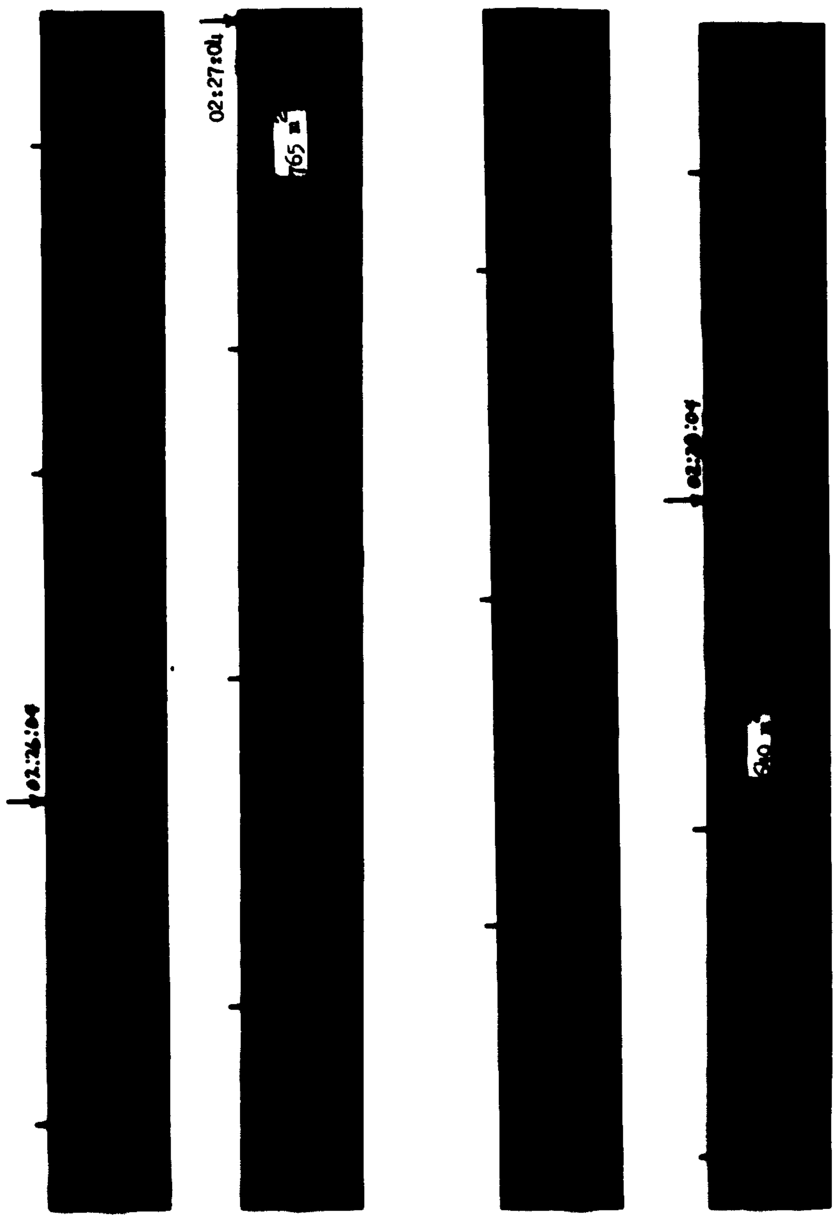


FIG. 3 PLATE 9

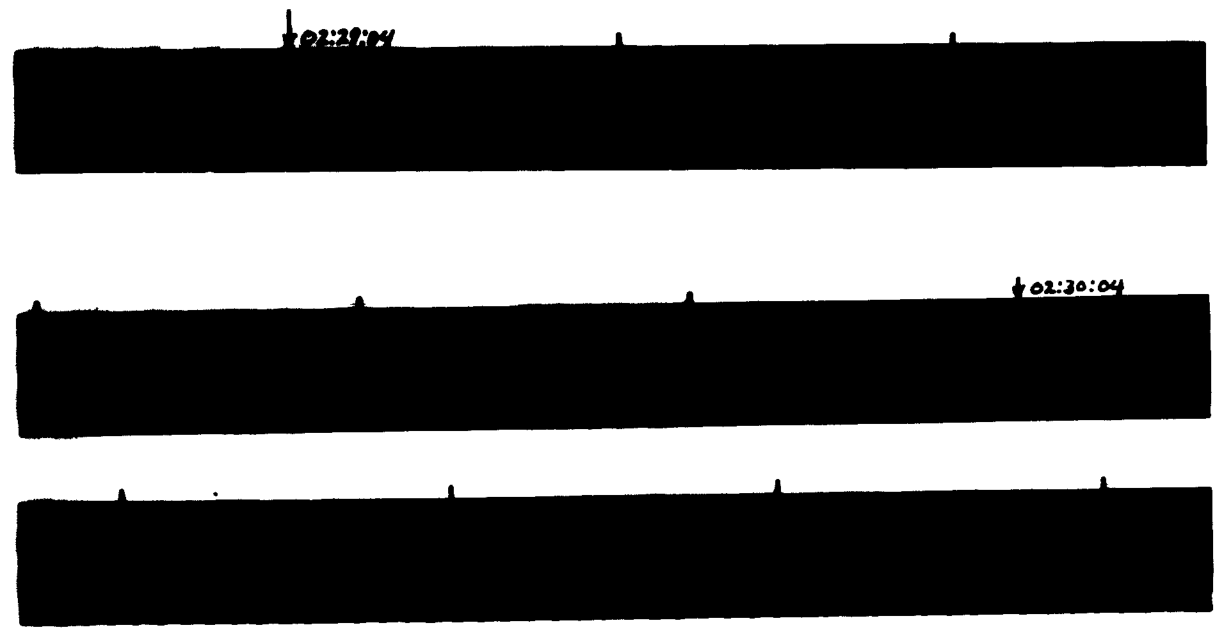


FIG. 3 PLATE 10

ECHO I AMPLITUDE

Revolution 45

15 August 1960

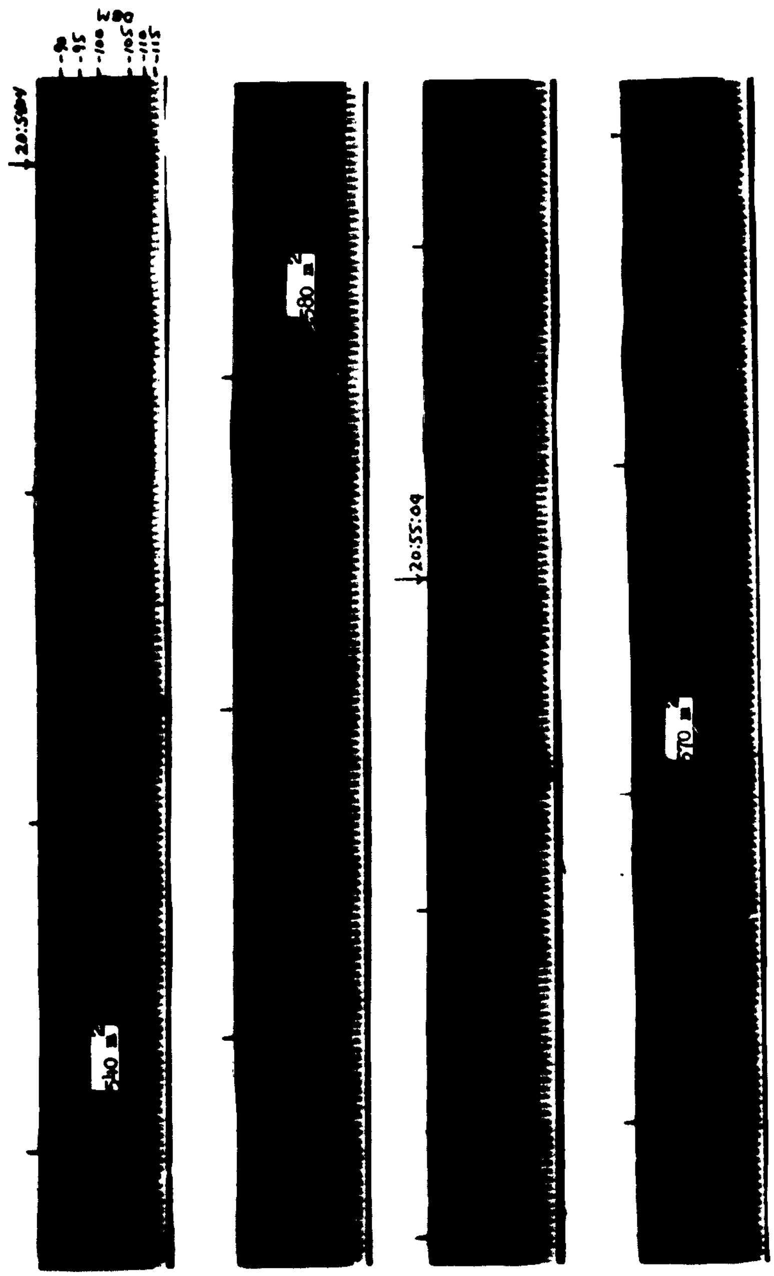


FIG. 4 PLATE 1

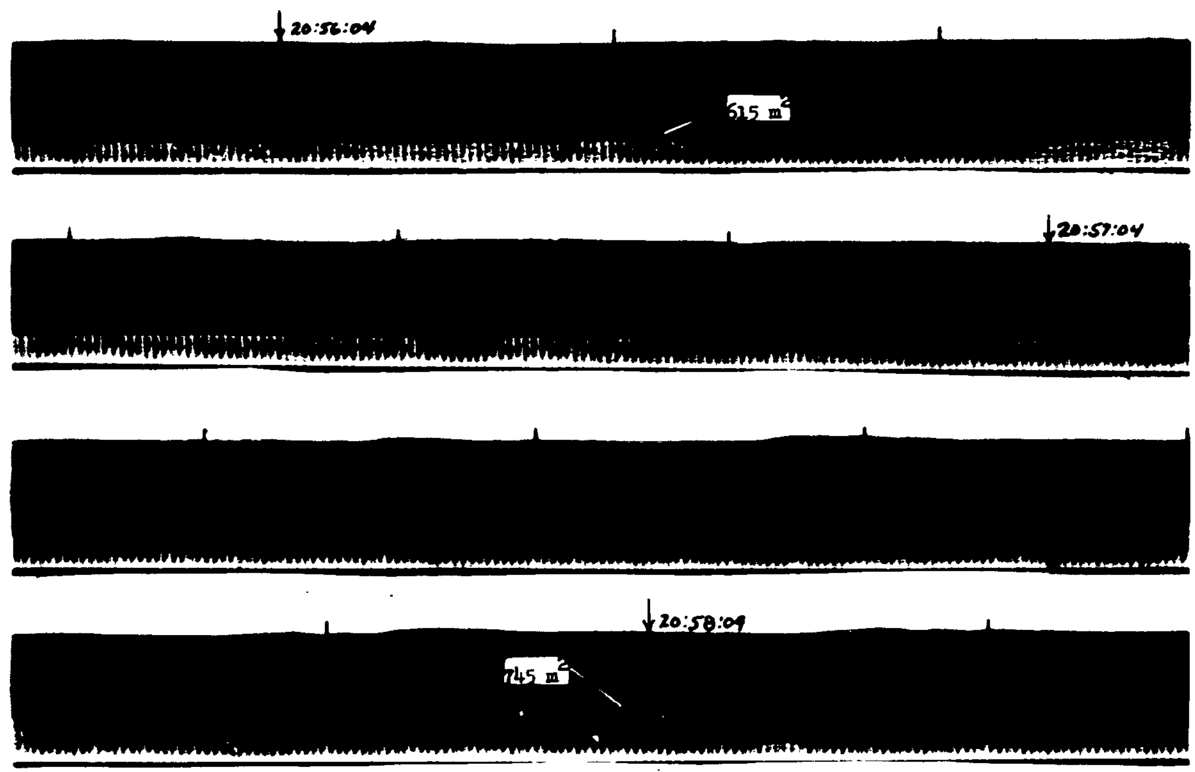


FIG. 4 PART 2

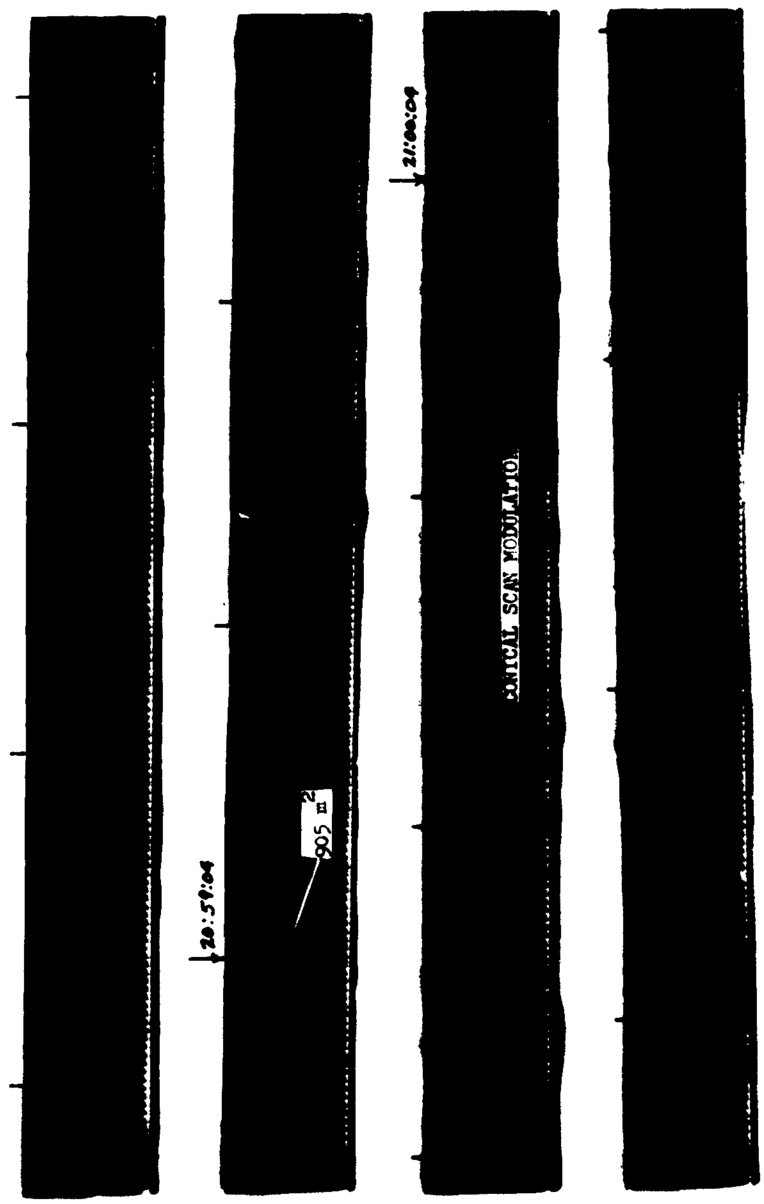


FIG. 4 PLATE 3

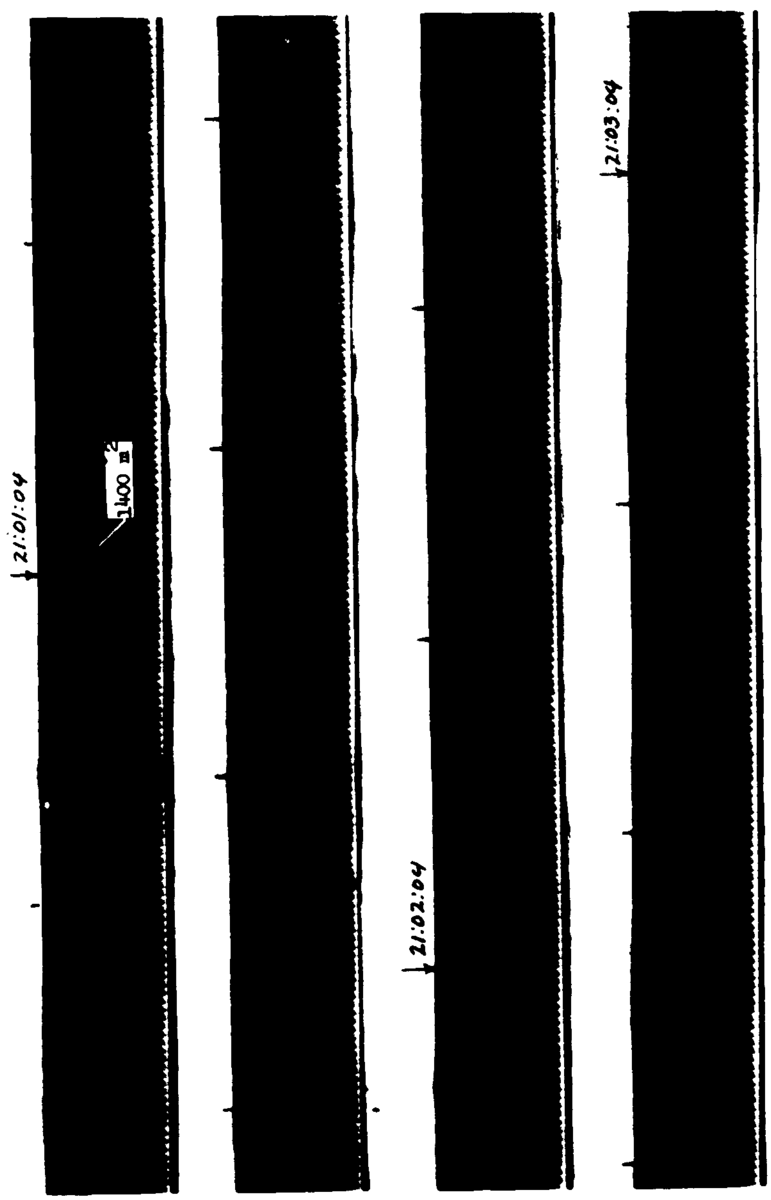


FIG. 4 PLATE 4

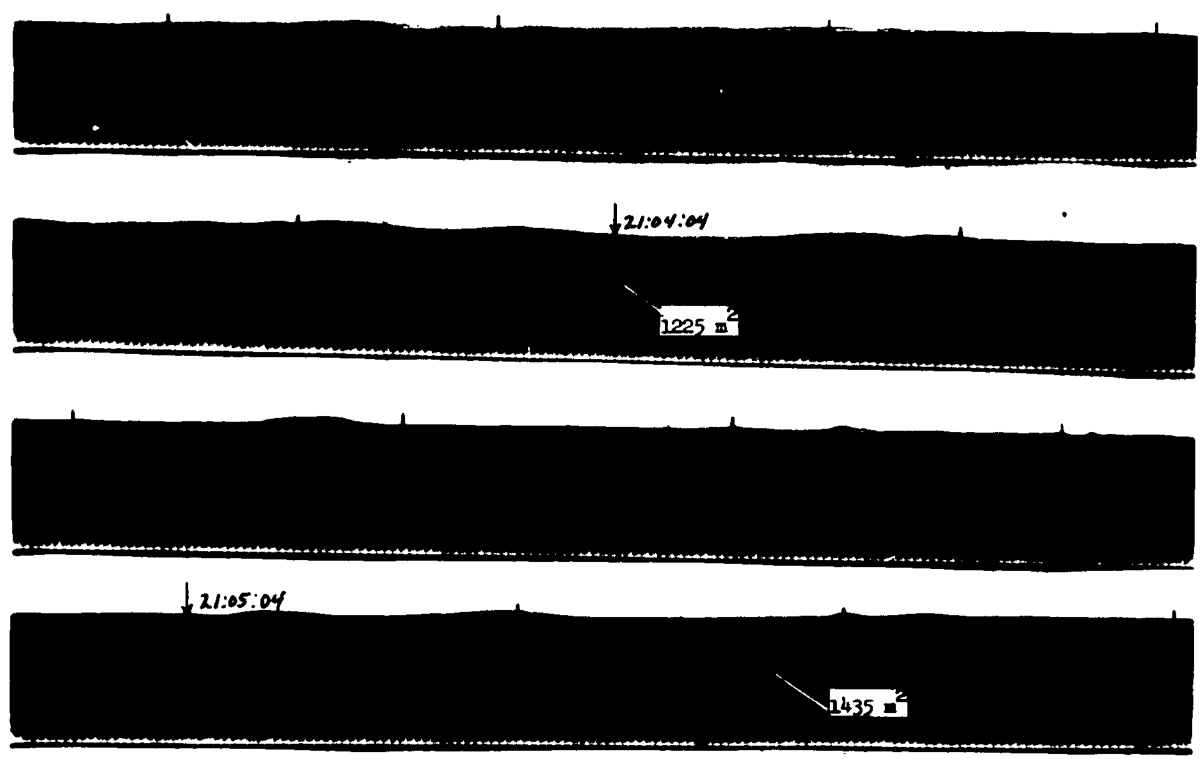


FIG. 4 PLATE 5

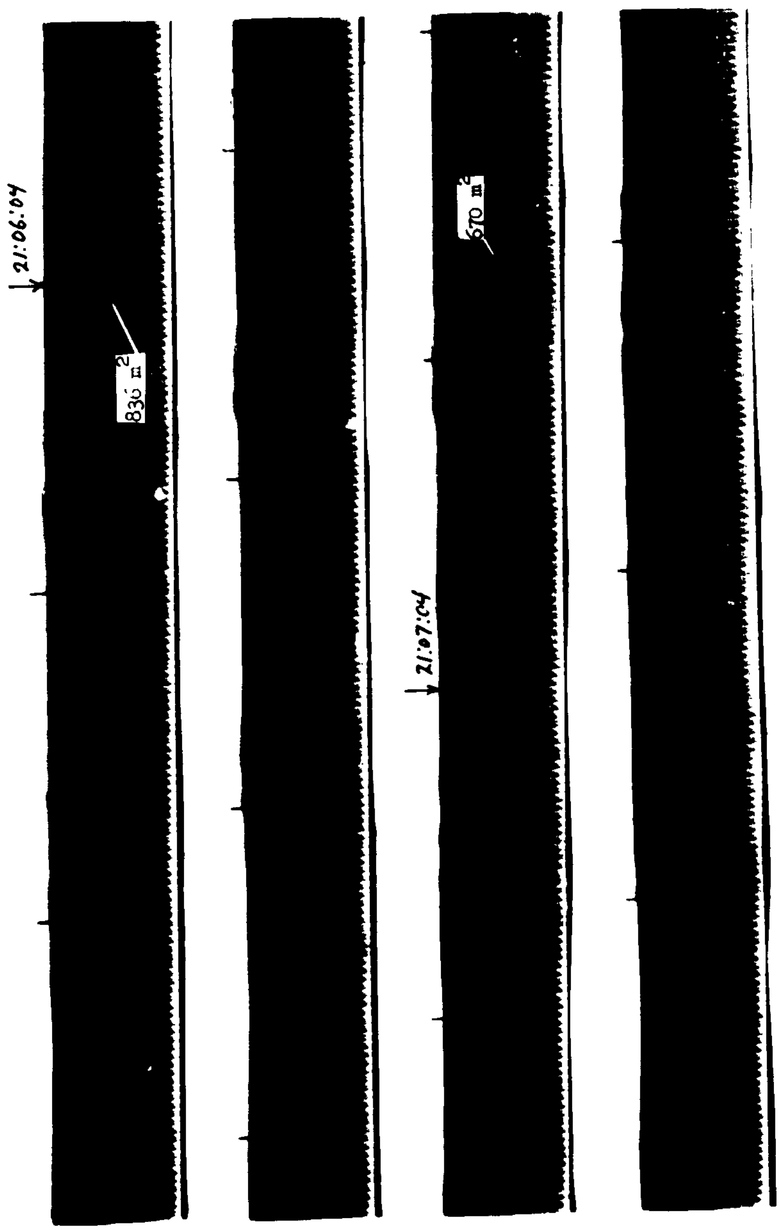


FIG. 4 FLAT 6

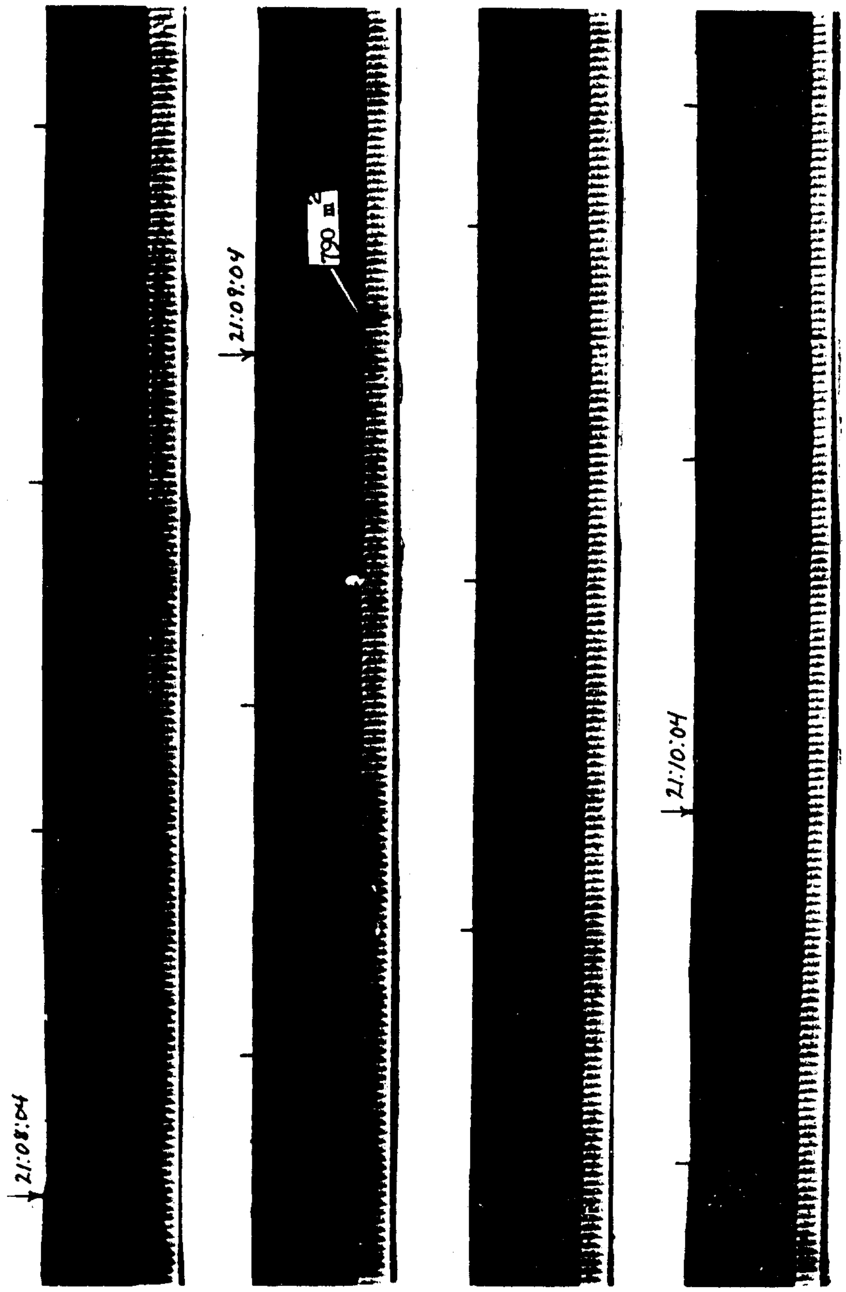


FIG. 4 PLATE 7

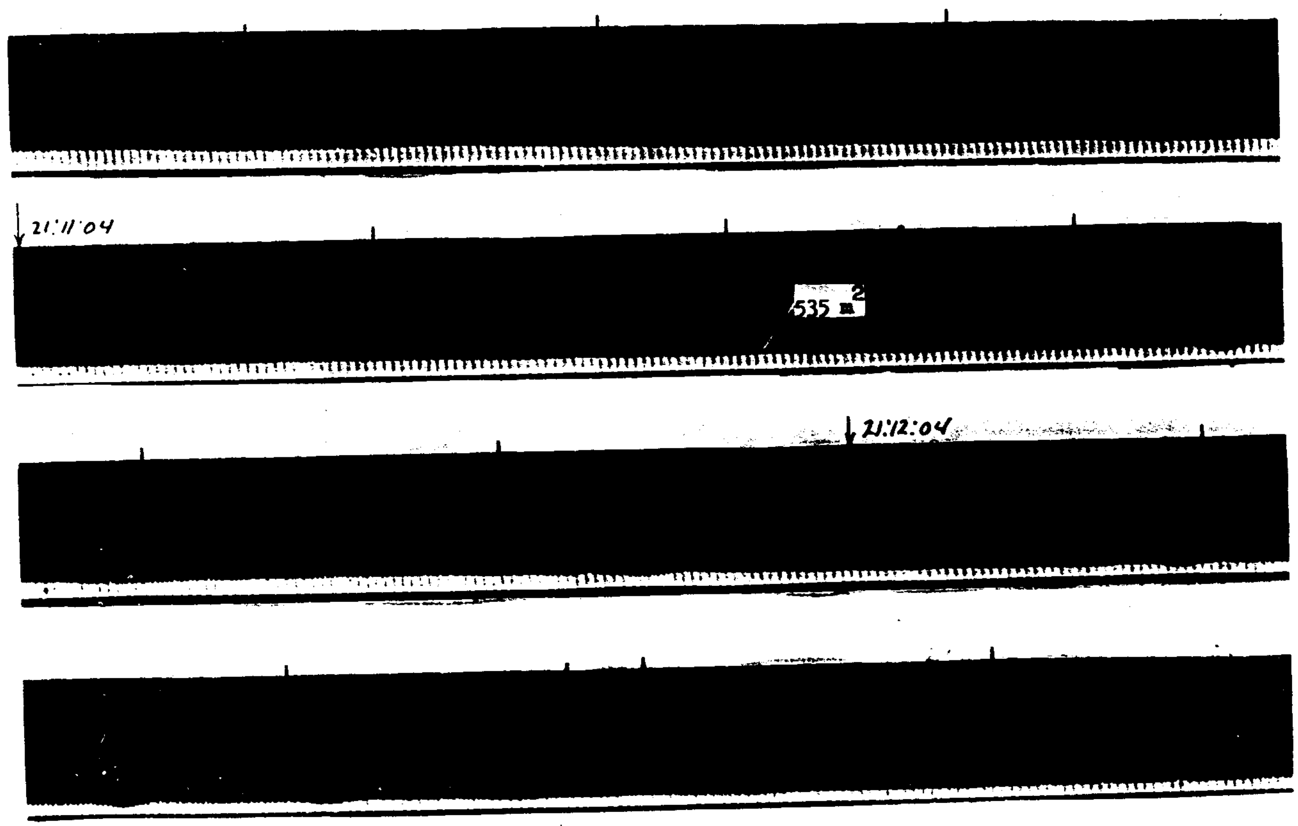


FIG. 4 PLATE 8

ECHO I AMPLITUDE

Revolution 167

25 August 1960

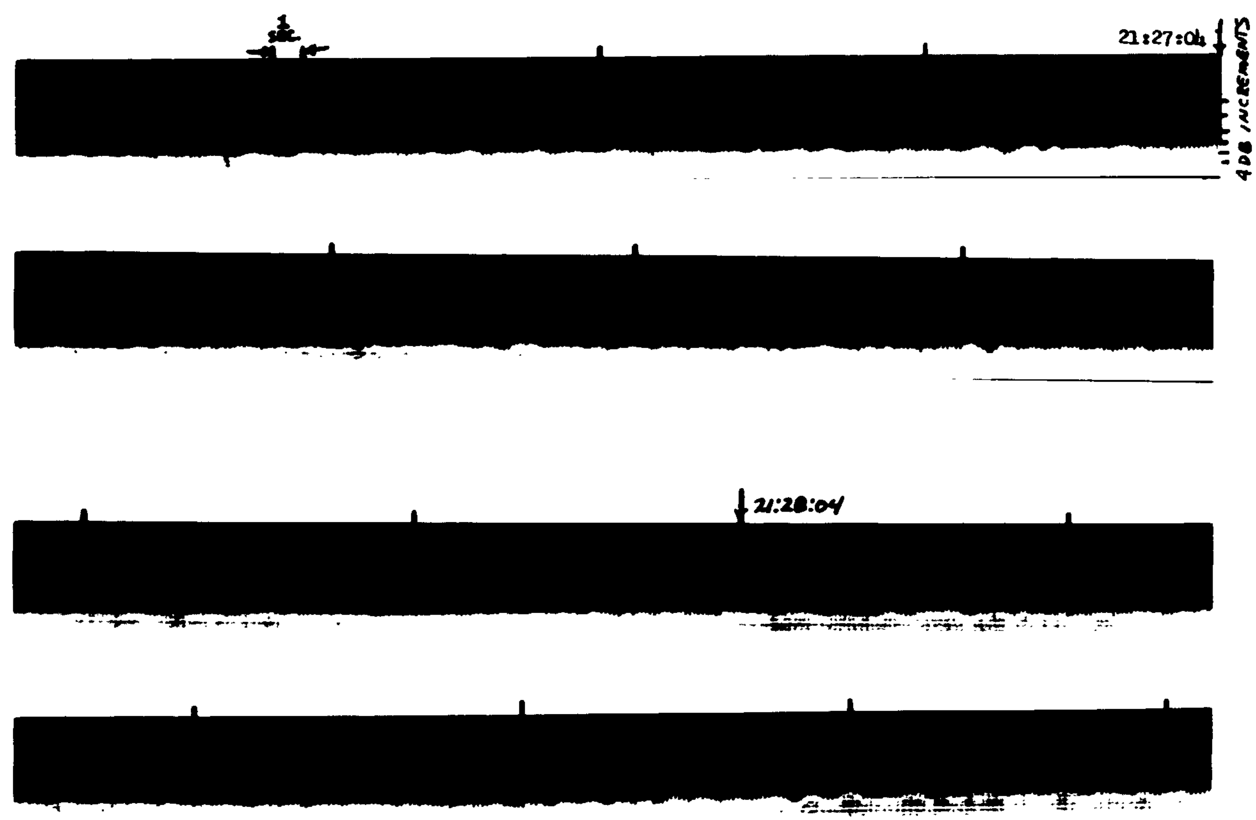


FIG. 5 PLATE 1

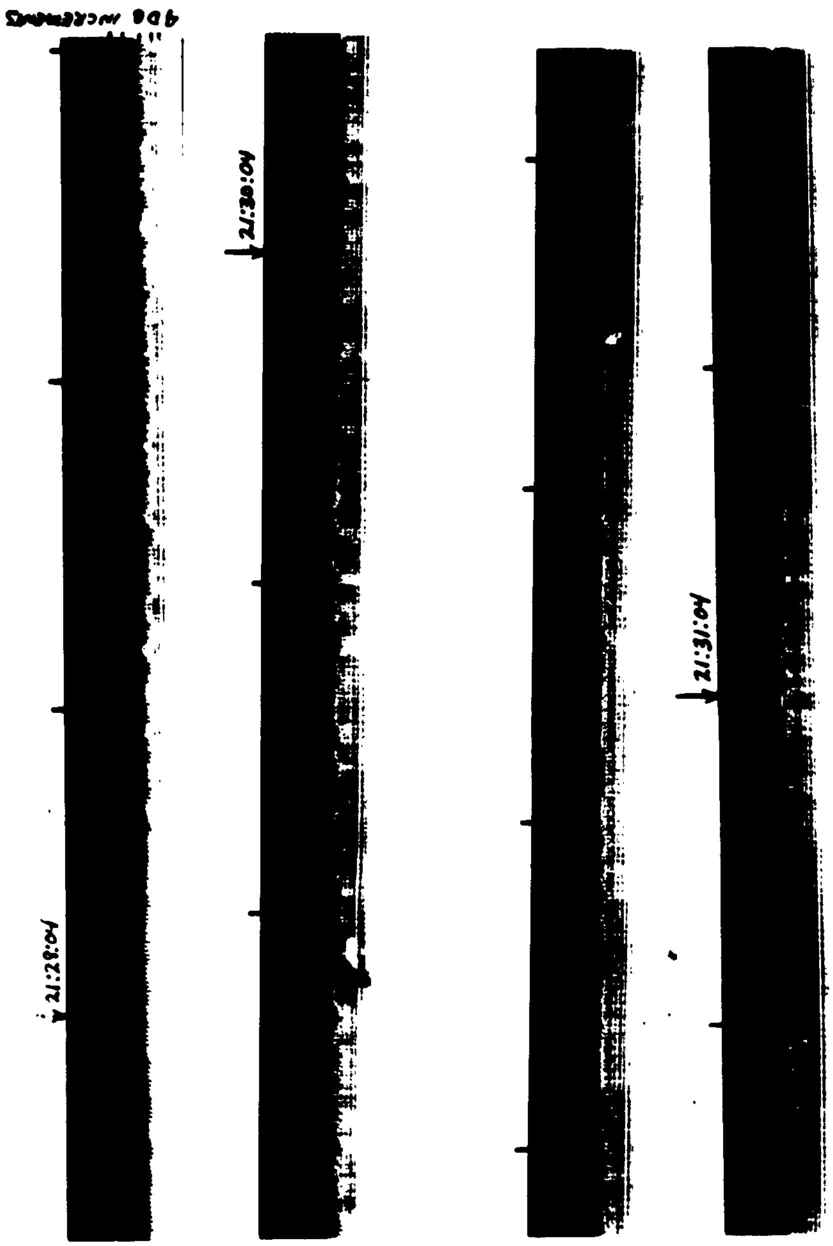


FIG. 5 PLATE 2

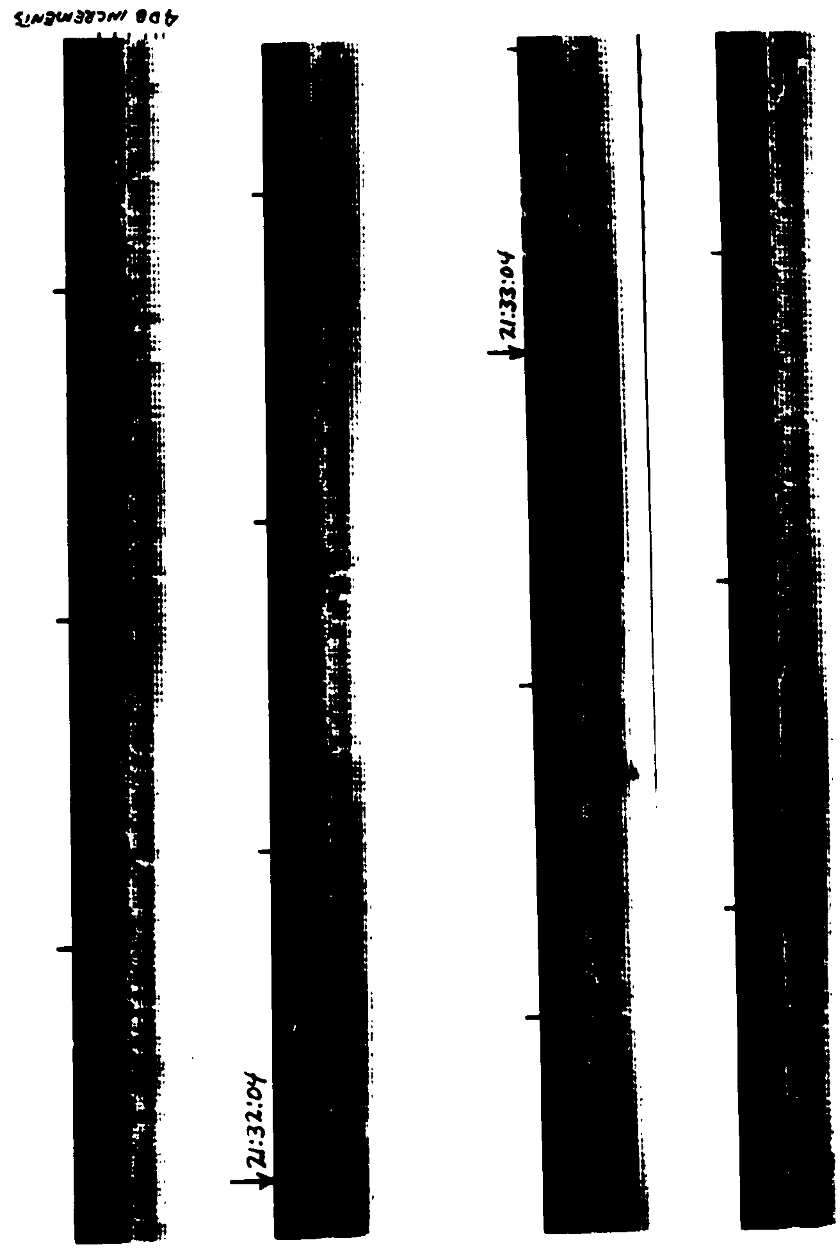


Fig. 5 PLATE 3

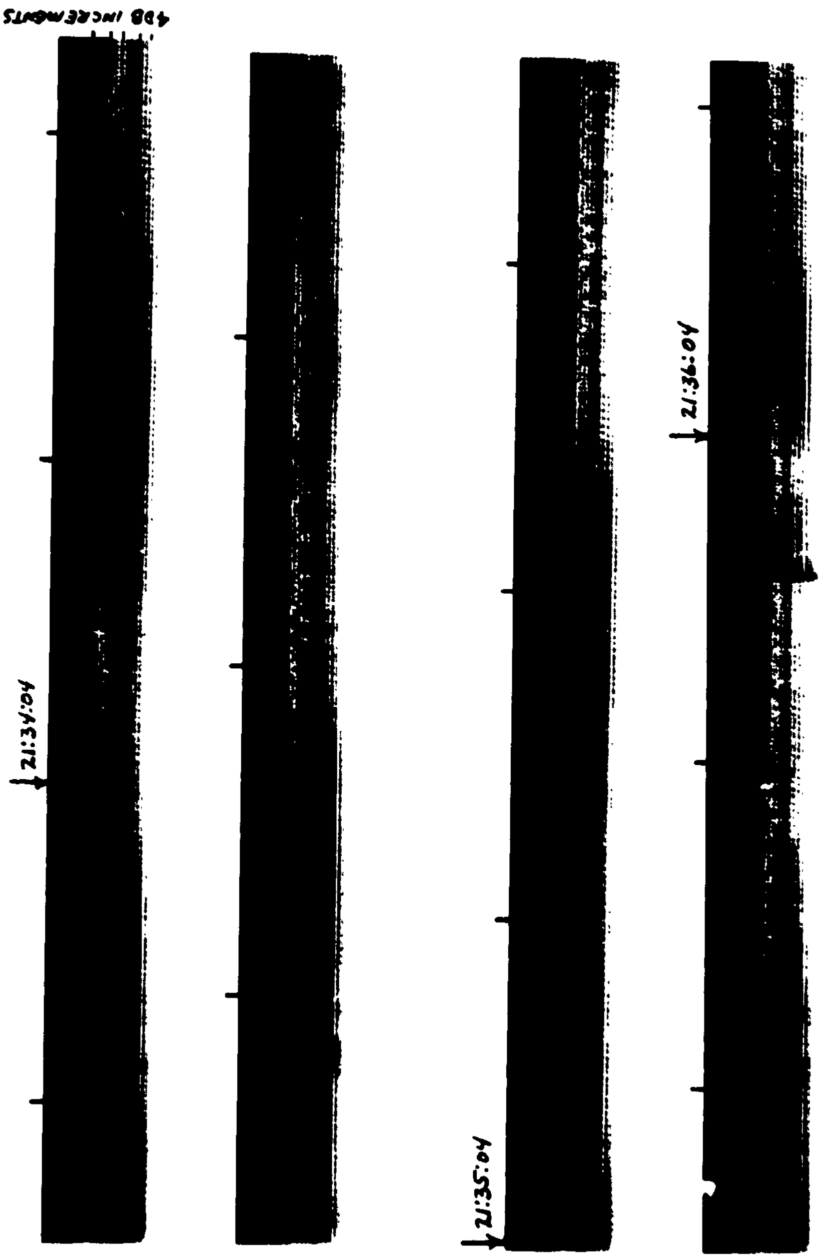


FIG. 5 PLATE 4

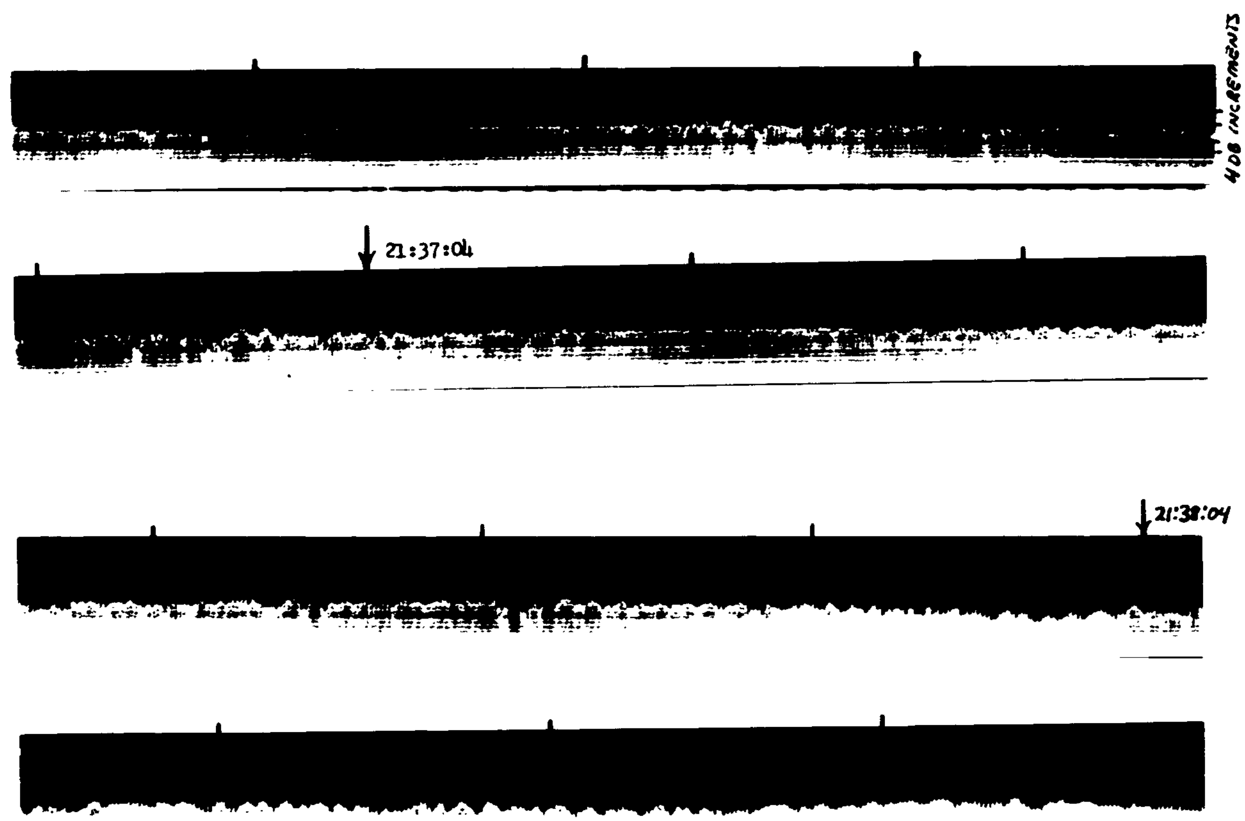
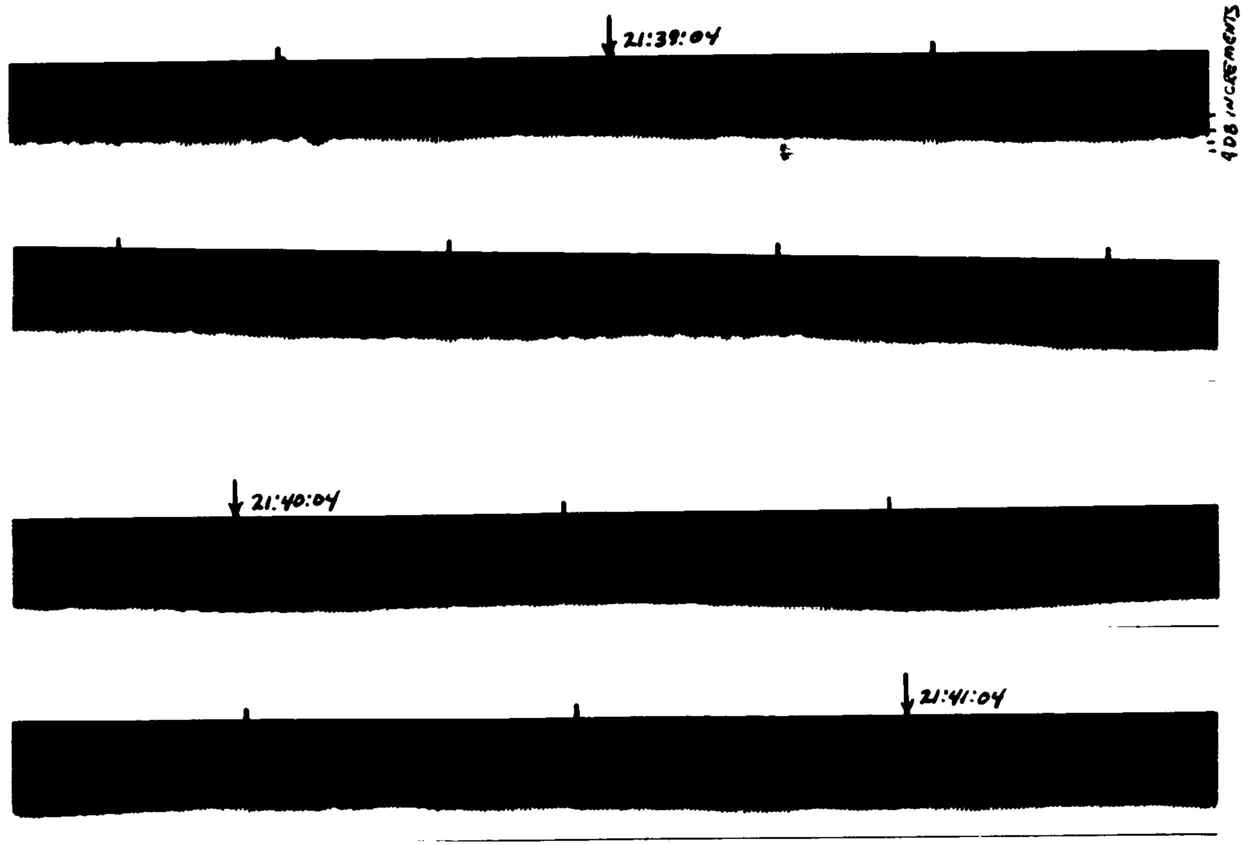
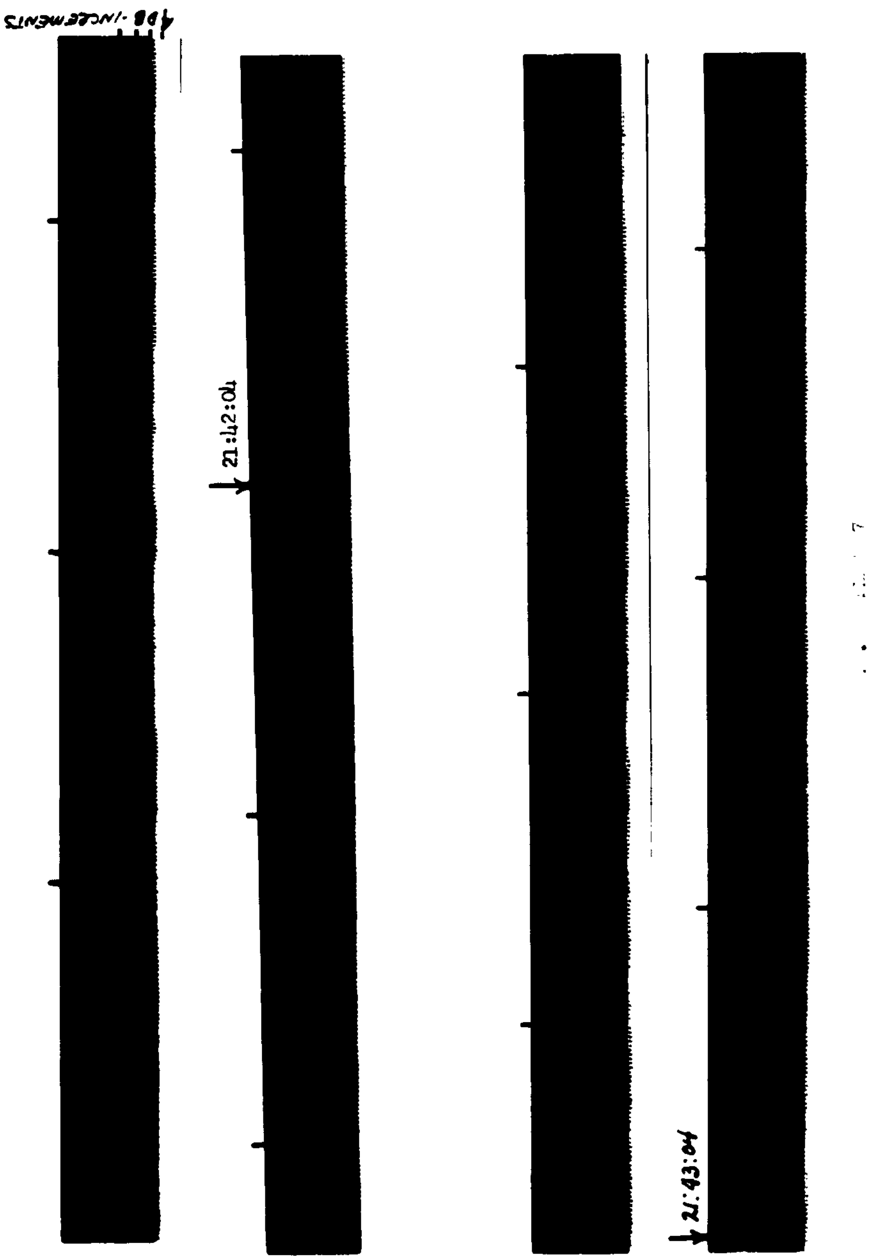


FIG. 5 PART F



F.G. 5 PLATE 6


4DB-INCREMENTS
21:42:04
21:43:04

ECHO I AMPLITUDE

Revolution 179

26 August 1960

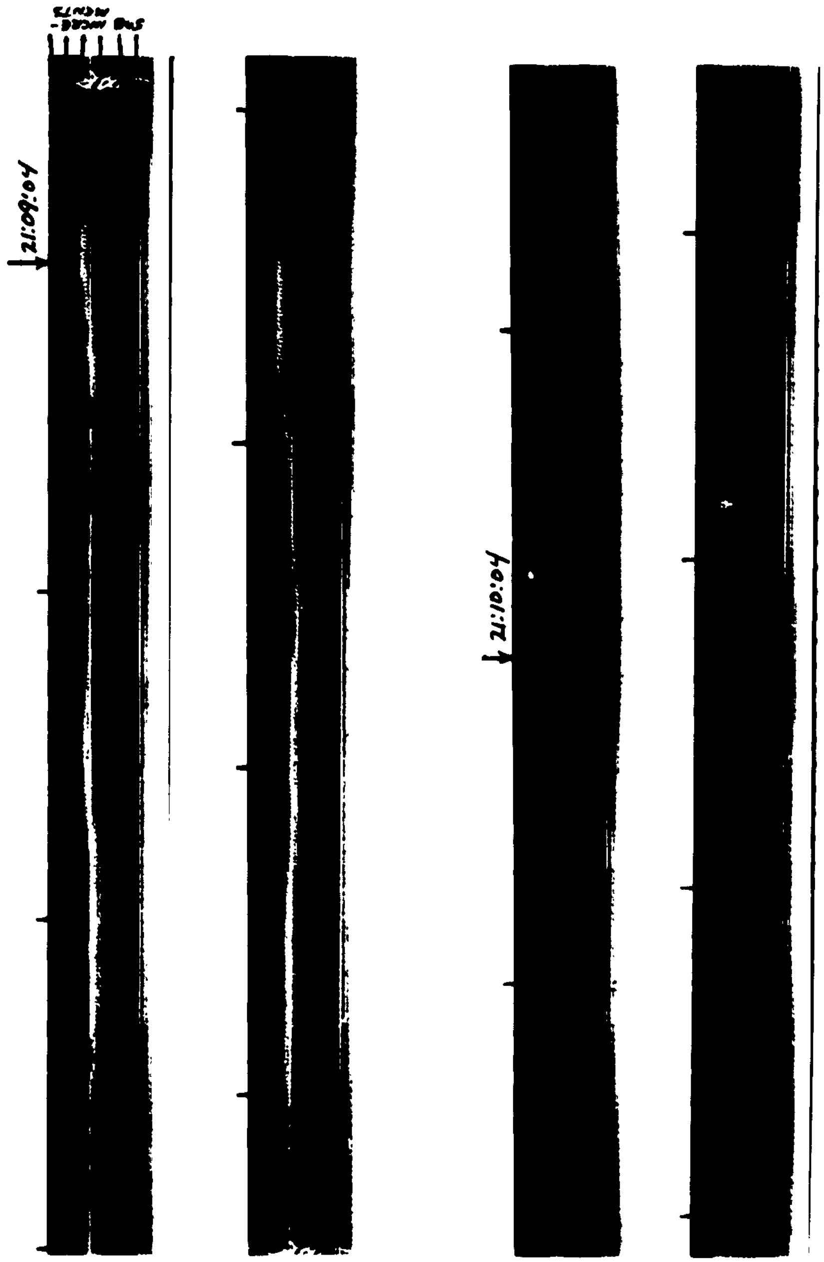


FIG. 6 PLATE 1

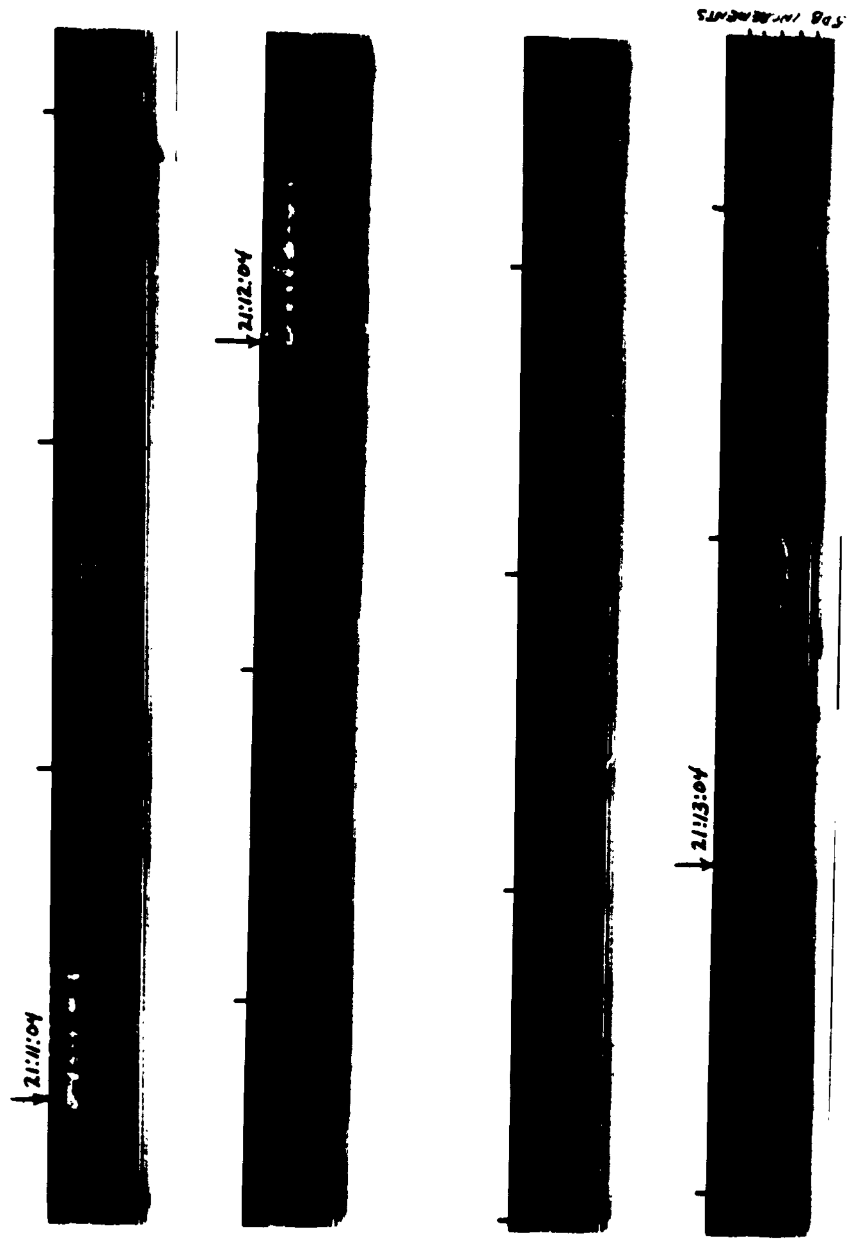


FIG. 6 PLATE 2

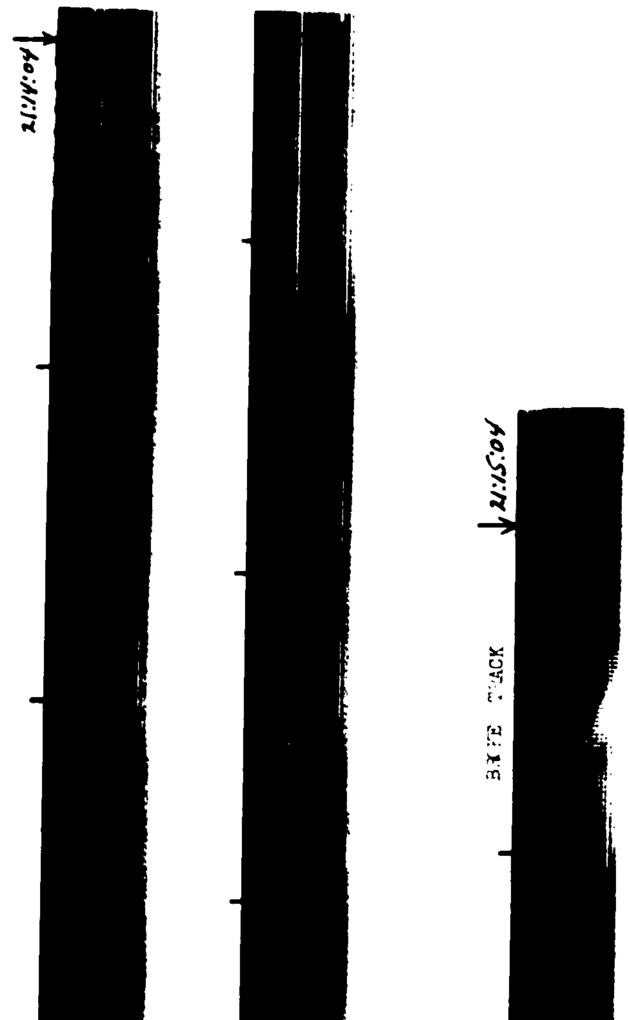


FIG. 6 PLATE 3

ECHO I AMPLITUDE

Revolution 636

3 October 1960

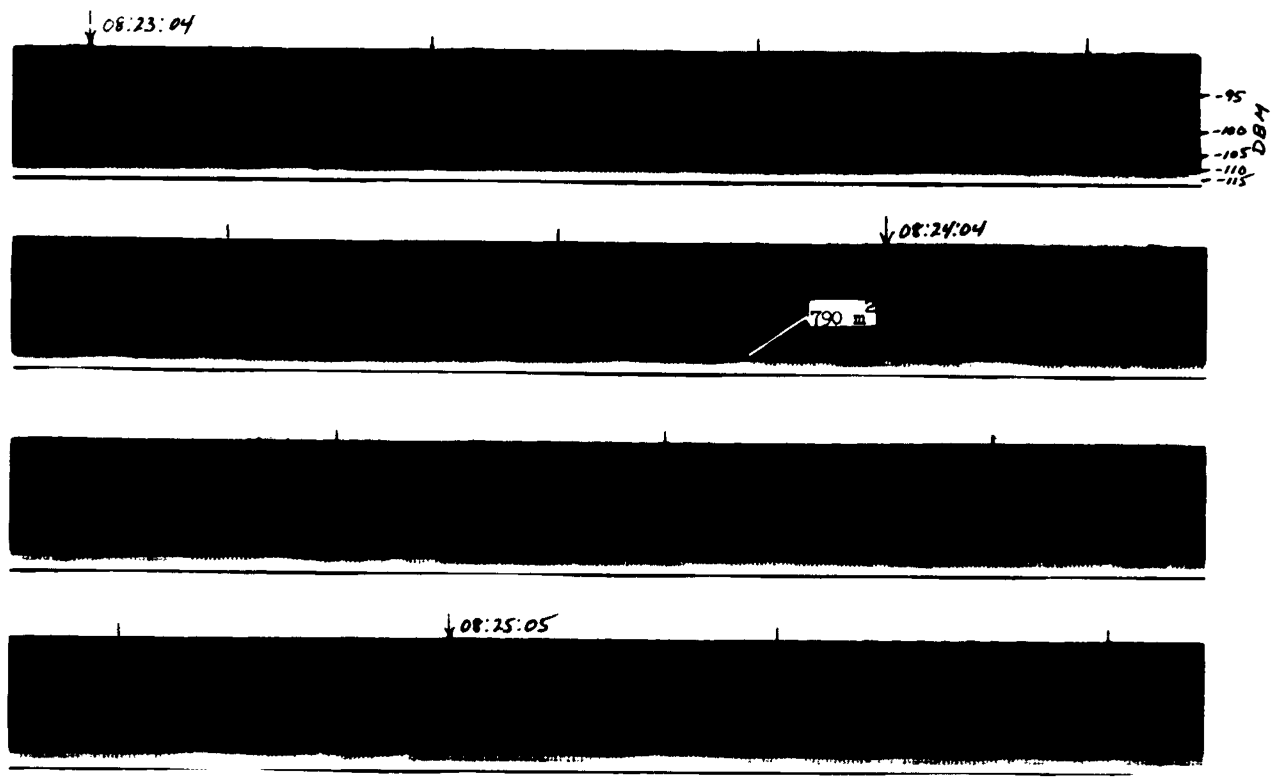


FIG. 7 [illegible] 1

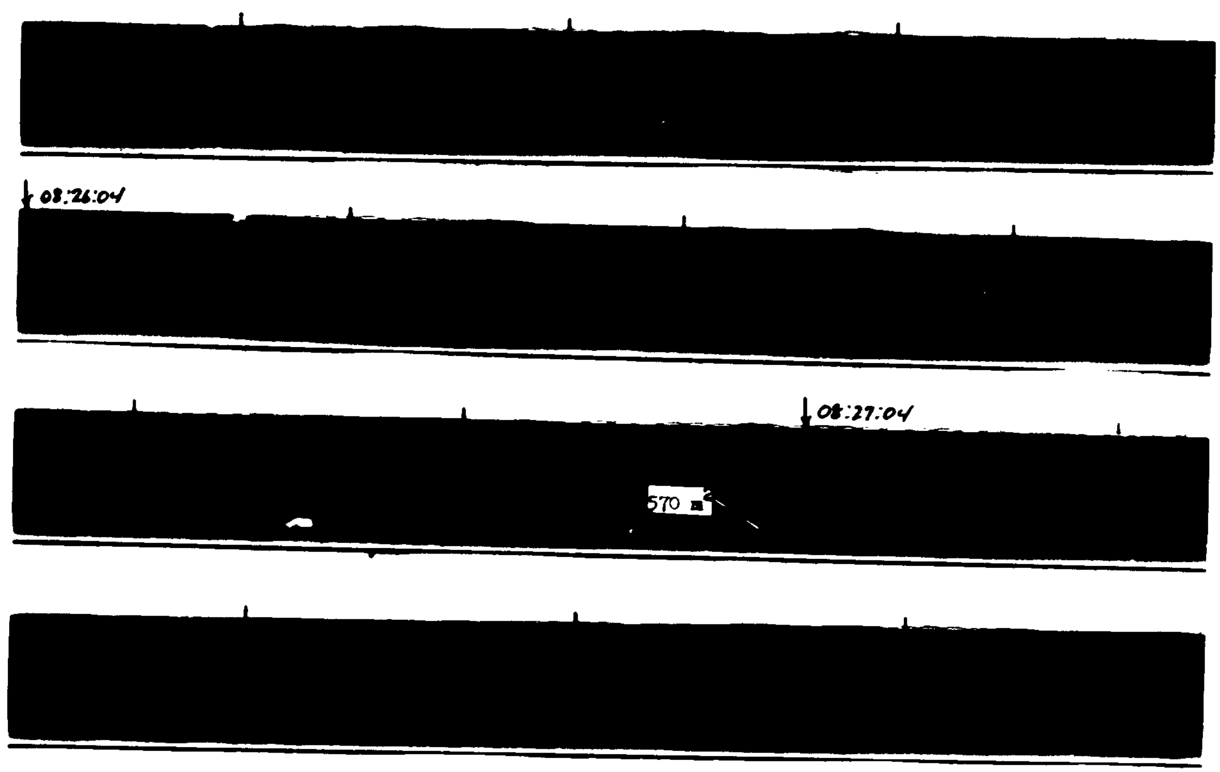
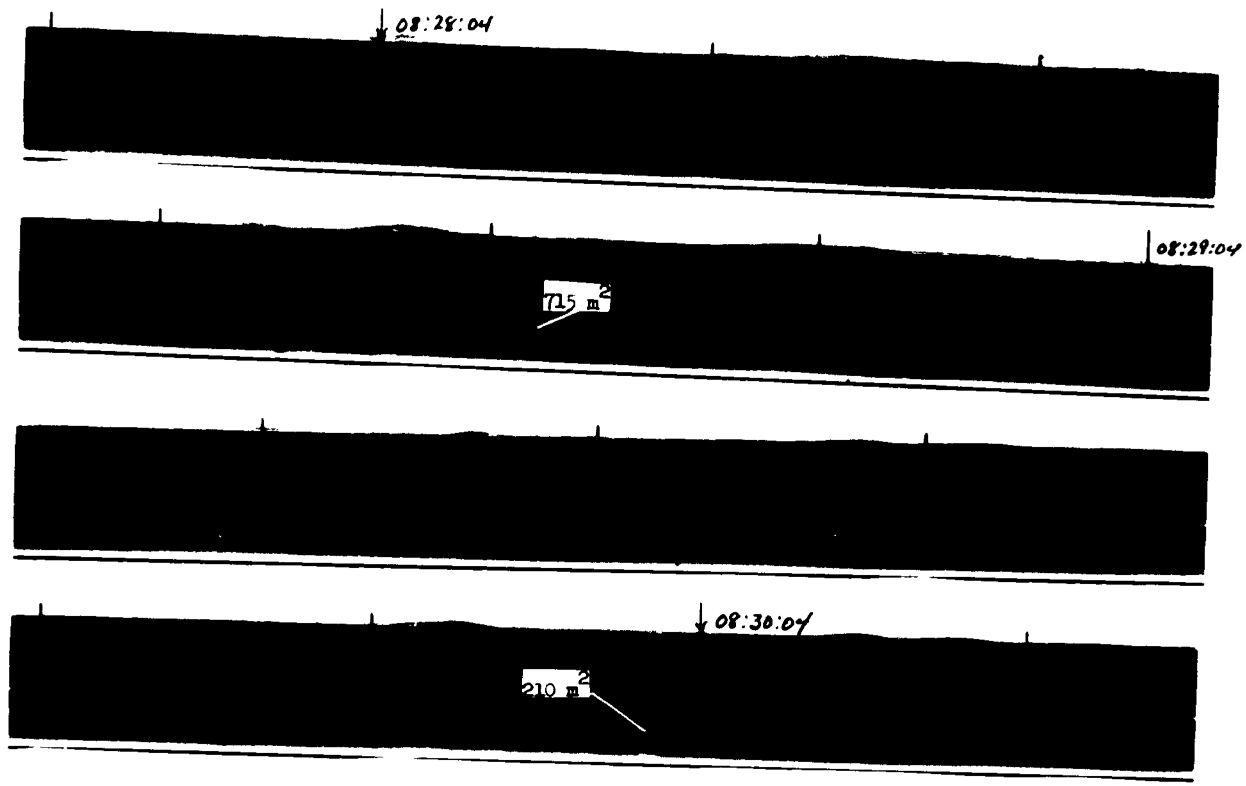


FIG. 7 PLATE 2



G. 7 HAT 3

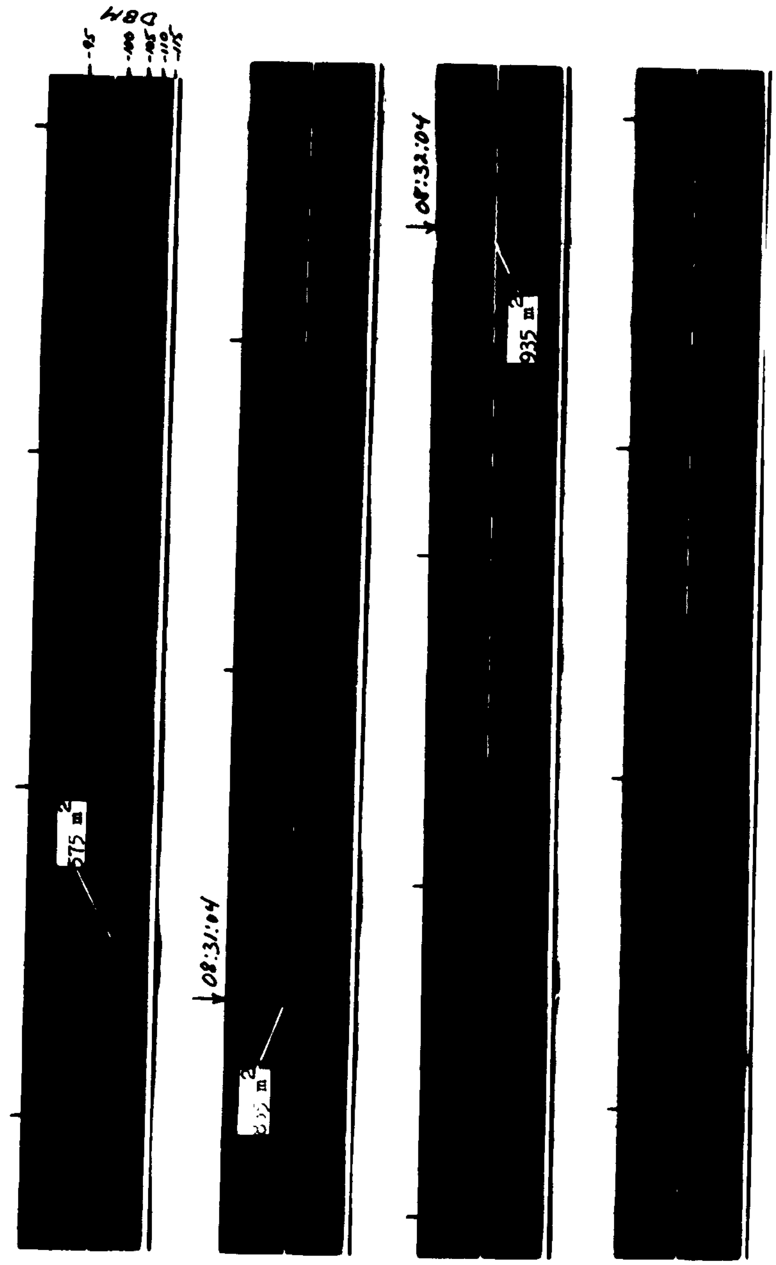


FIG. 7 PLATE 4

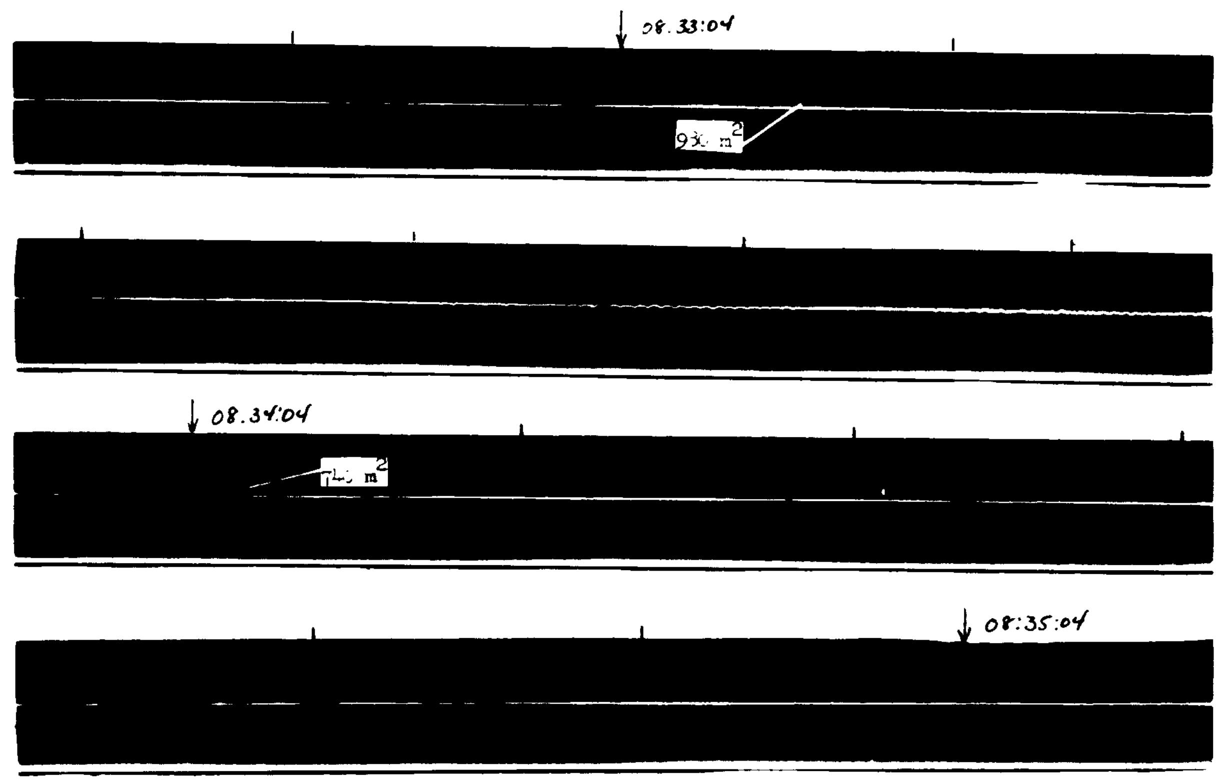


FIG. 7 FLAT- 5

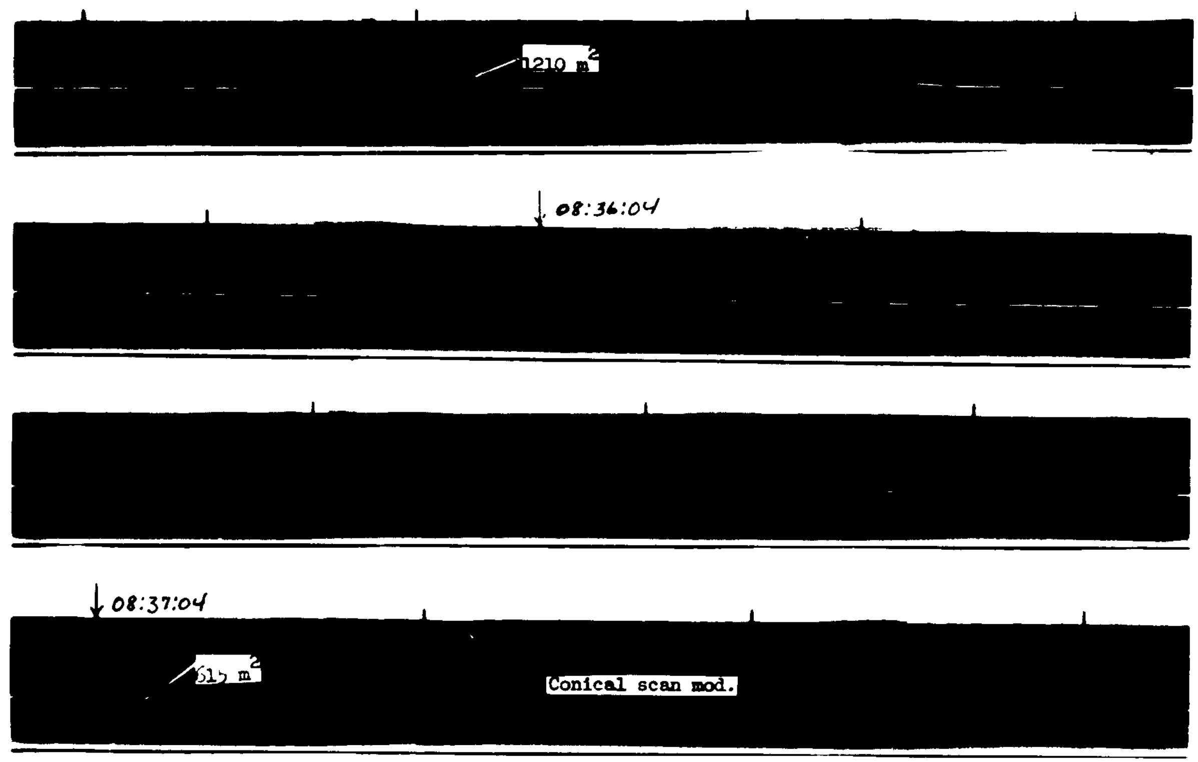


FIG. 7

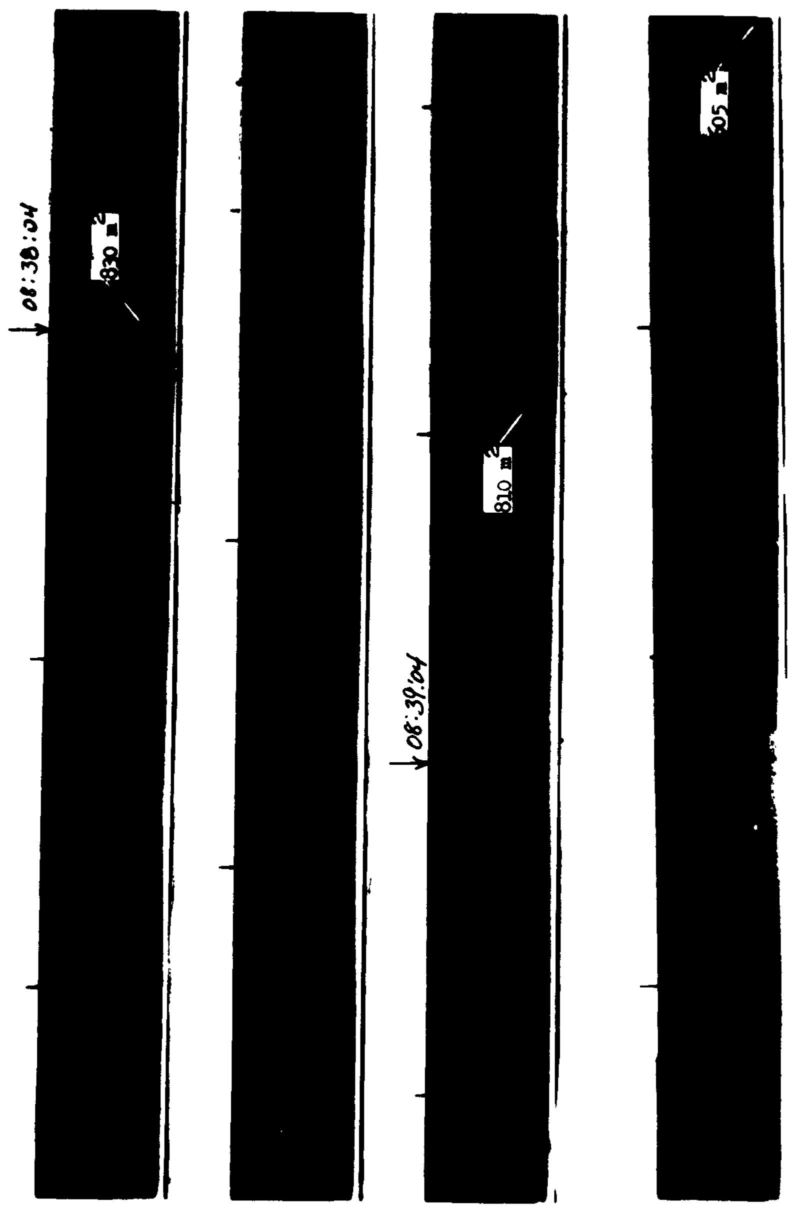
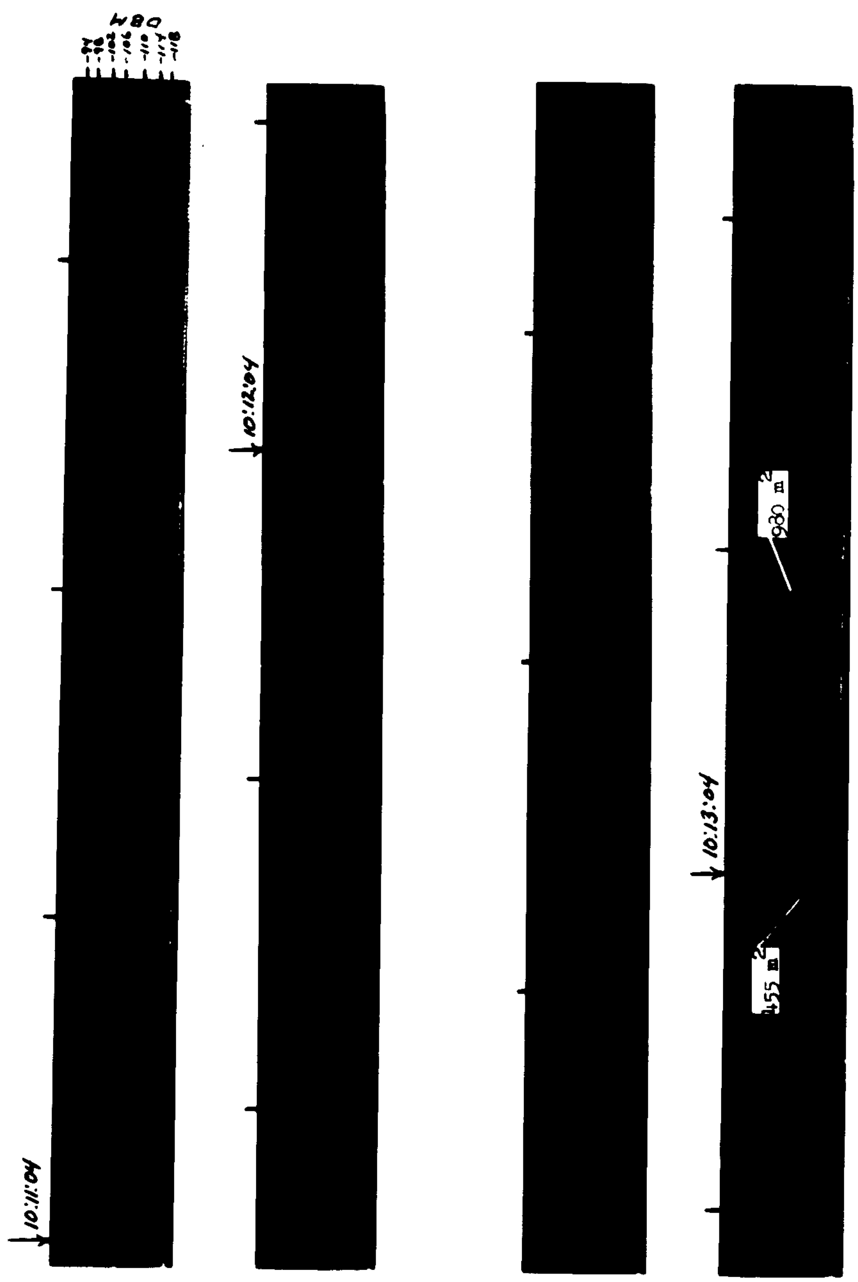


FIG. 7 PLATE 7

ECHO I AMPLITUDE

Revolution 942

28 October 1960



DBM
-94
-98
-102
-106
-110
-114
-118
10:11:04
10:12:04
10:13:04
930 m²
455 m²

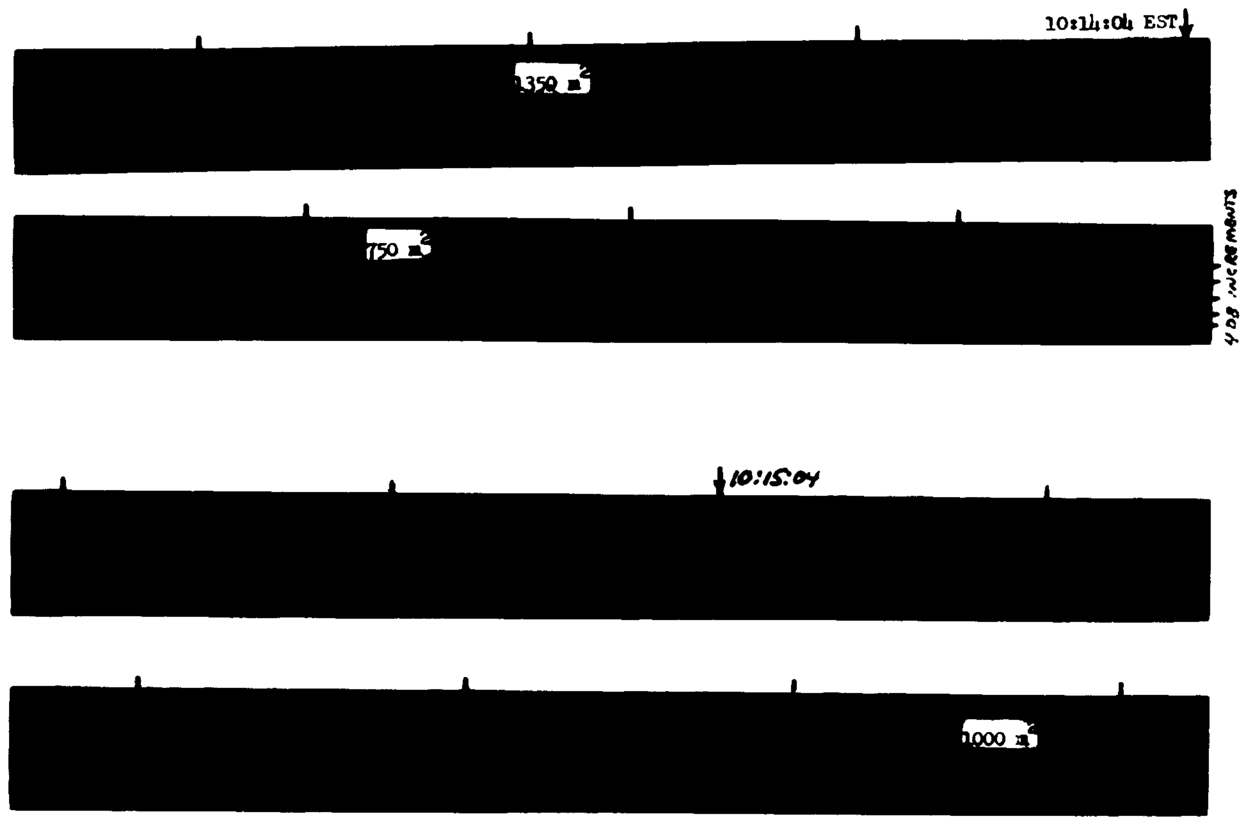


FIG. 8 PLATE 2

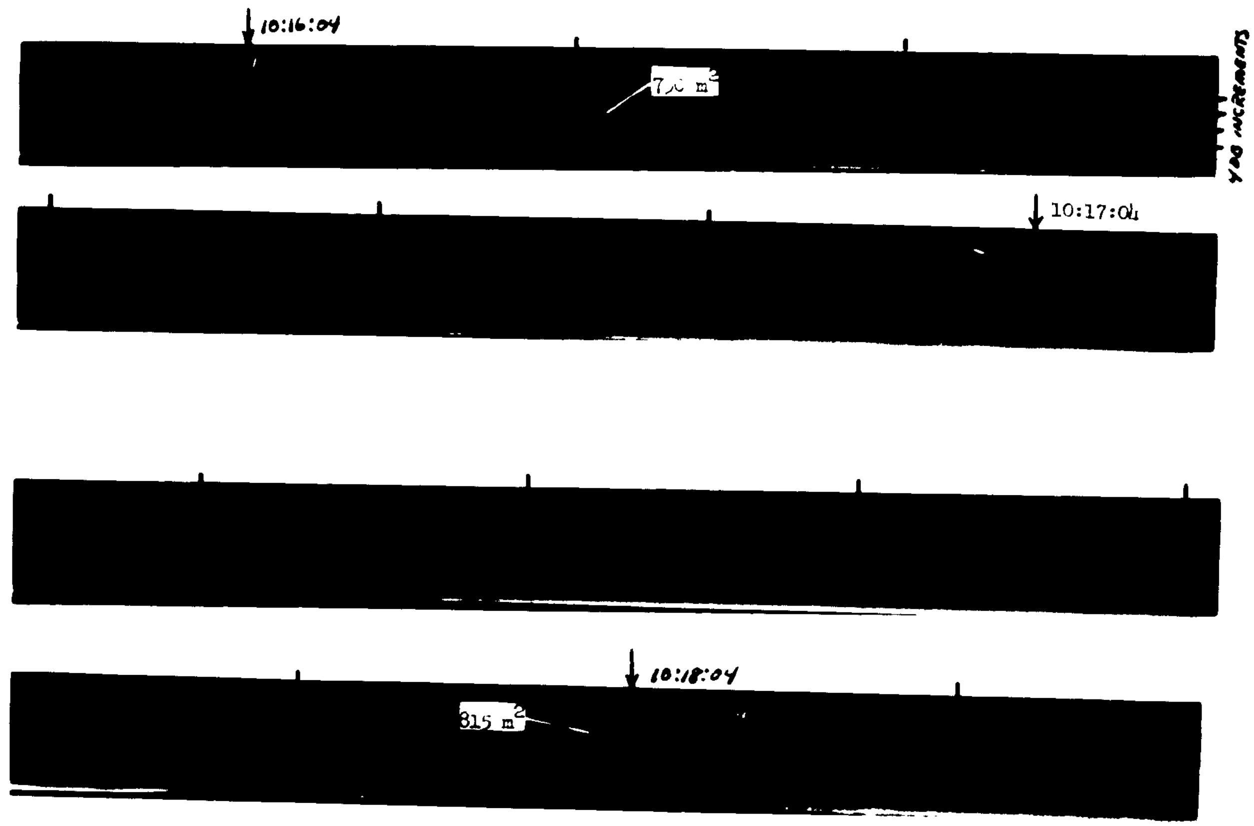


FIG. 8 PLATE 3

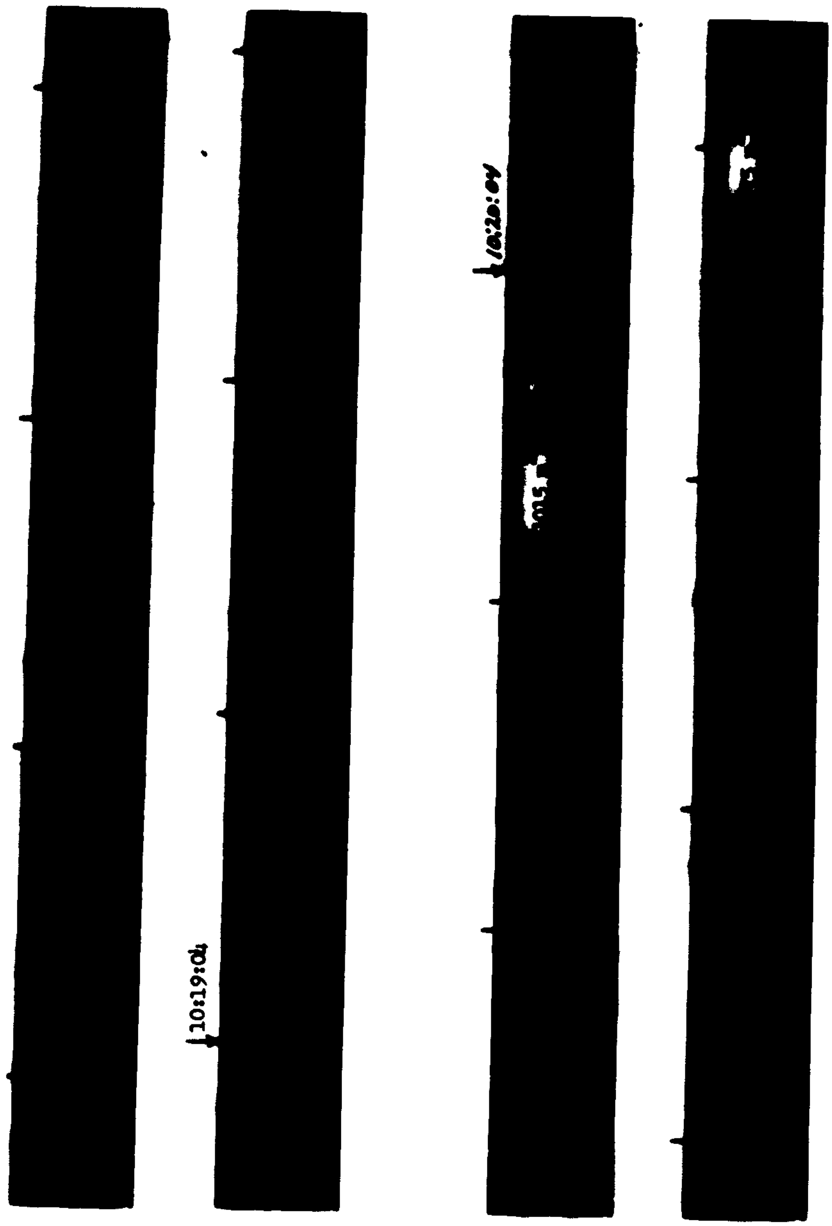


FIG. 8 PLATE 4

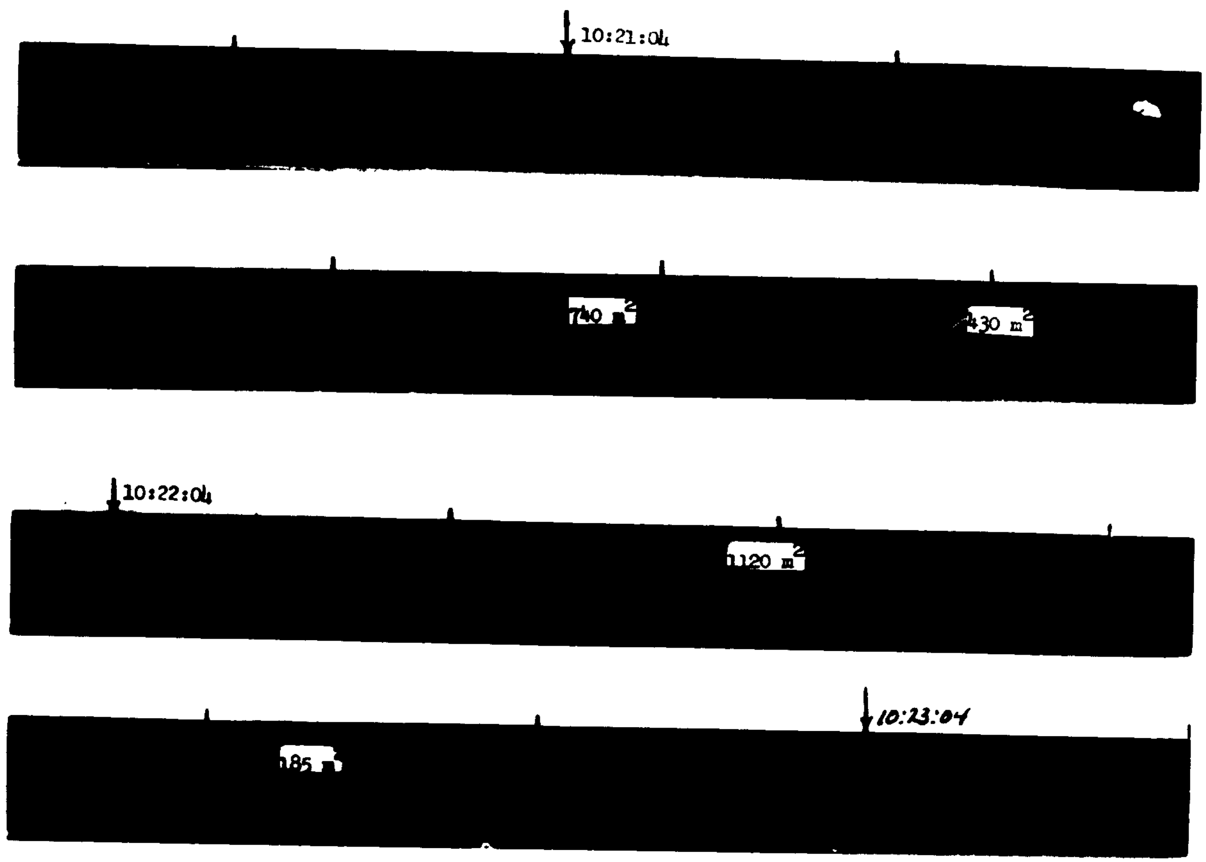


FIG. 8 [illegible] 5

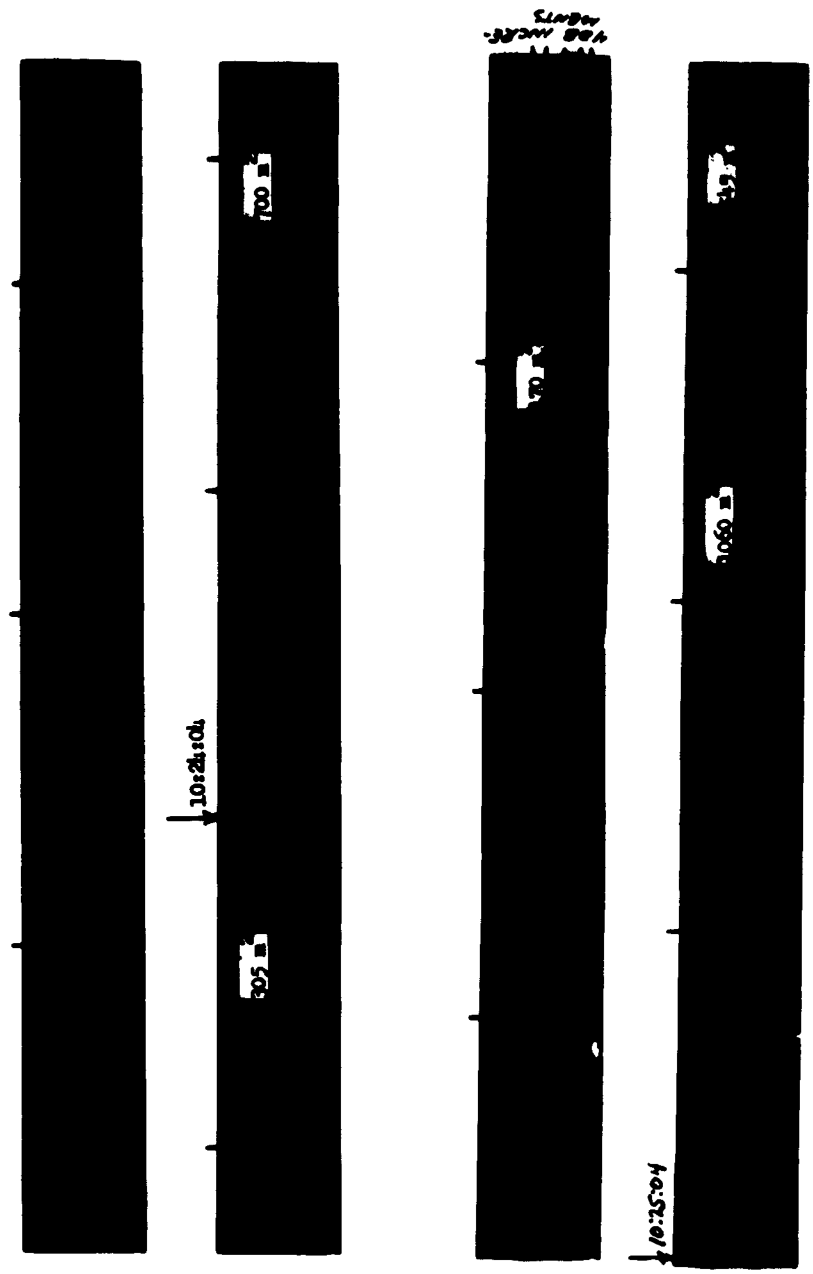


FIG. 8 PLATE 6

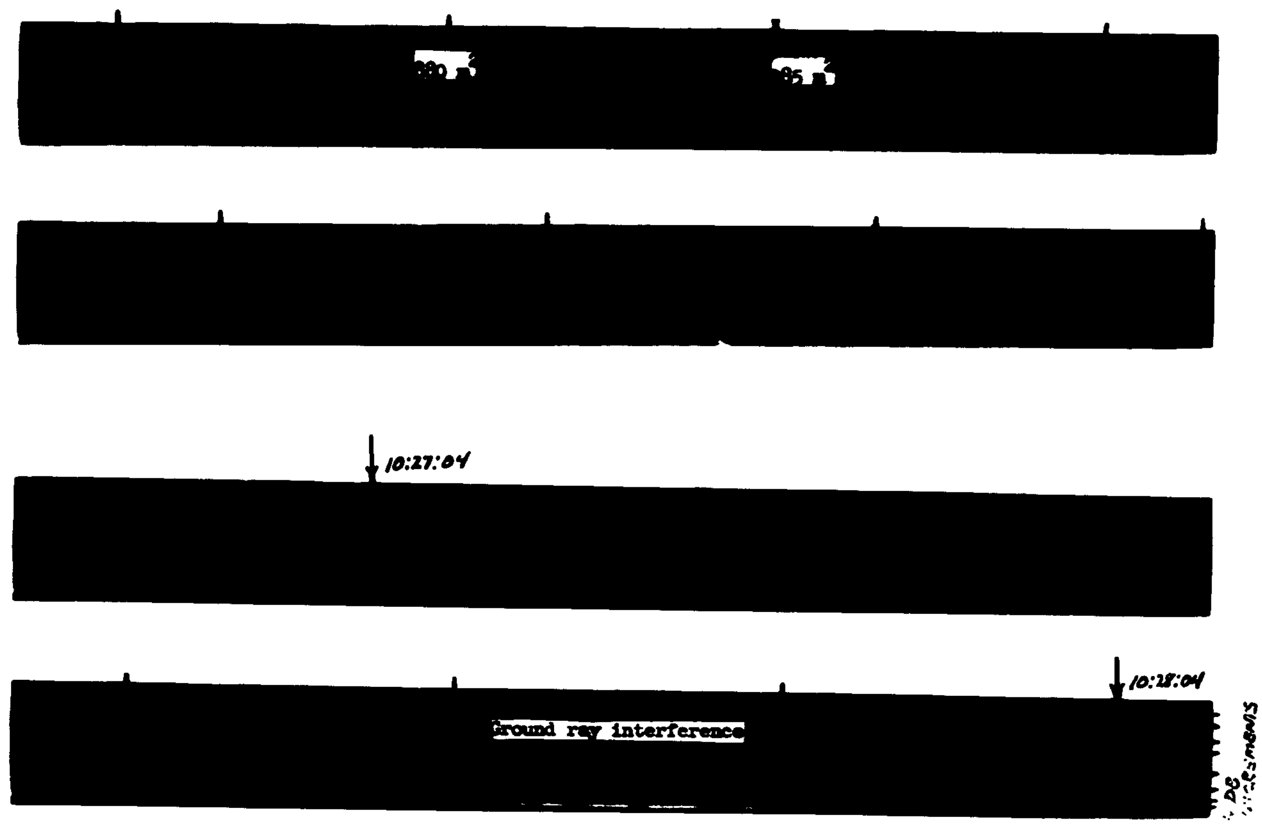


FIG. 8 PLATE 7

ECHO I AMPLITUDE

Revolution 1862

11 January 1961

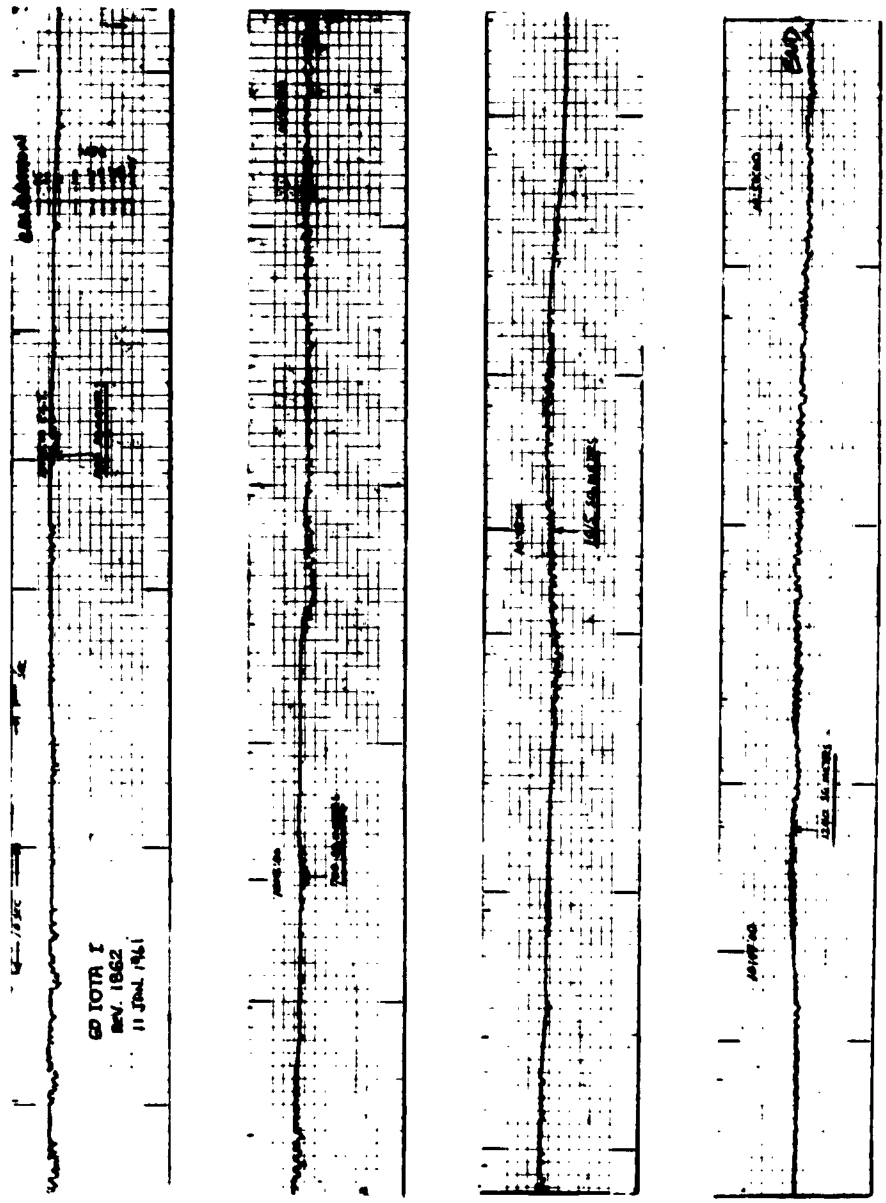


FIG. 9

ECHO I AMPLITUDE

Revolution 1944

18 January 1961

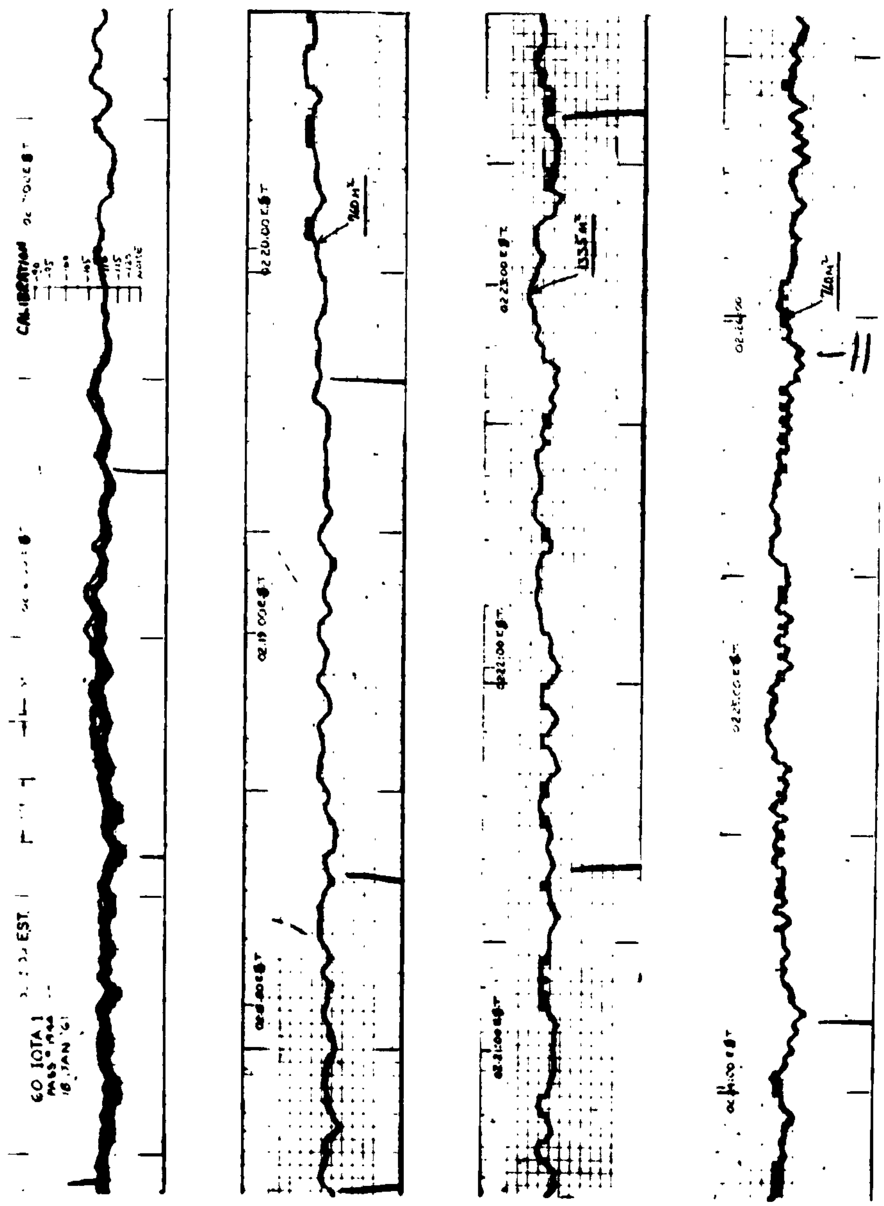


FIG. 10 PLATE 1

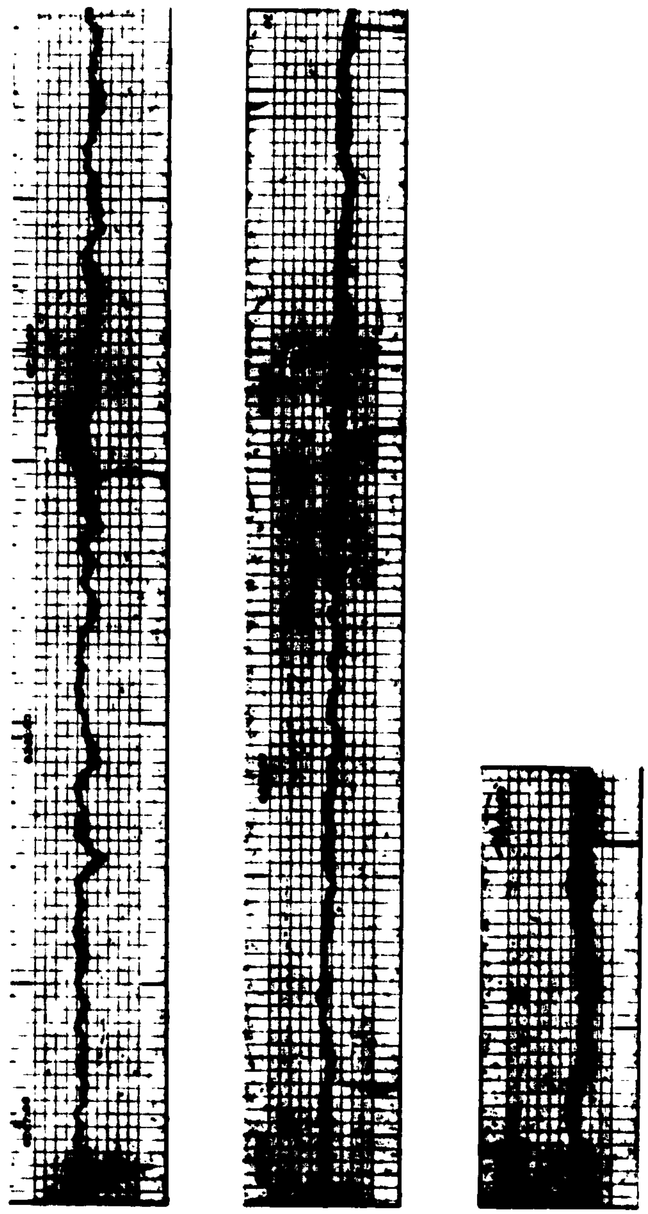


FIG. 10 PLATE 2

ECHO I AMPLITUDE

Revolution 3147

25 April 1961

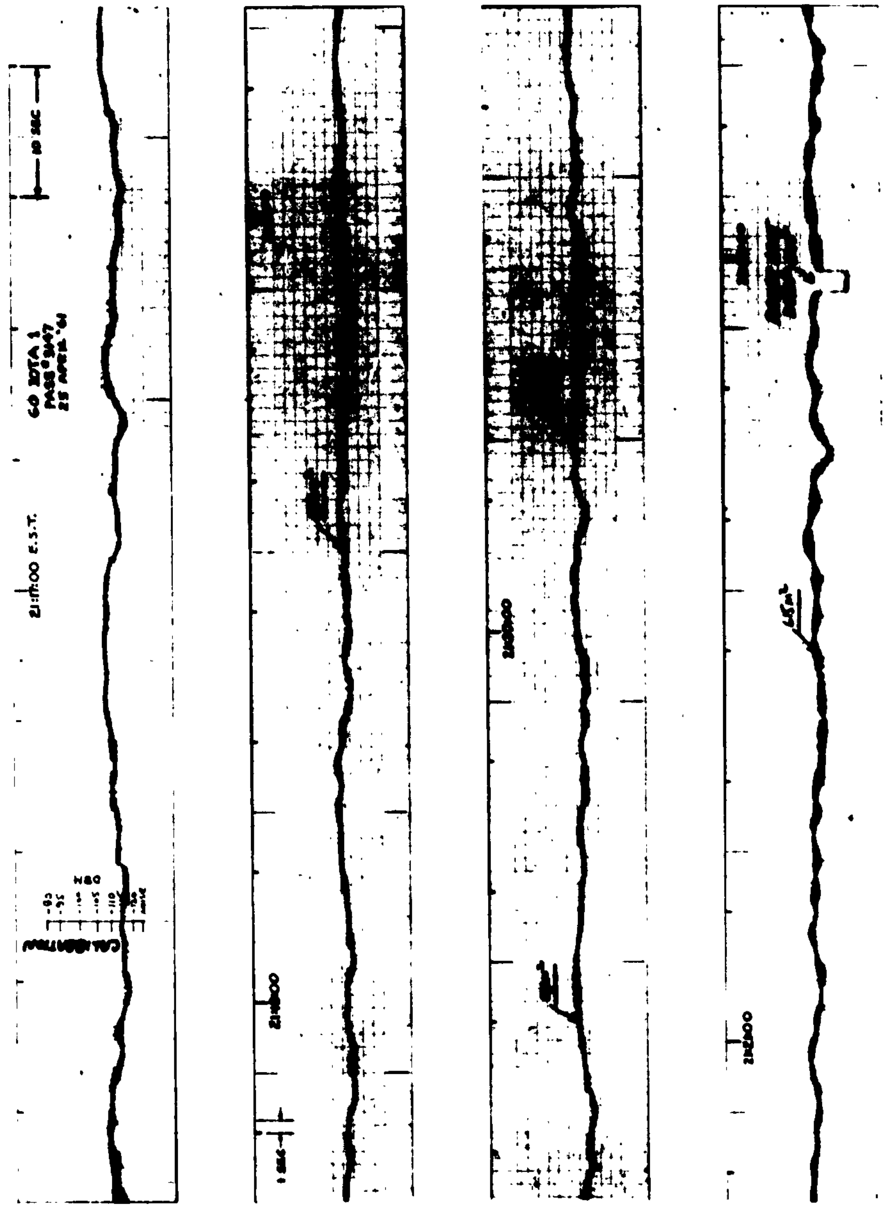


FIG. 11 PLATE 1

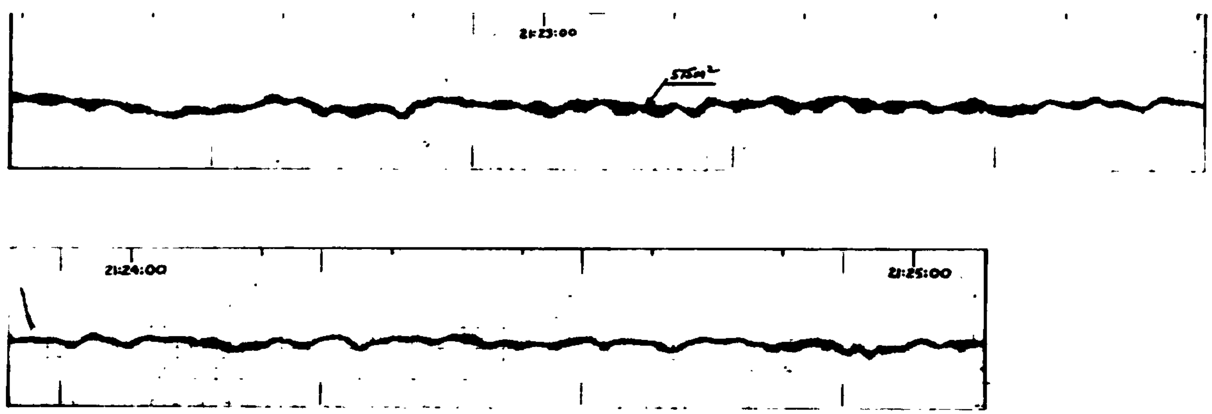


FIG. 11 PLATE 2

ECHO I AMPLITUDE

Revolution 3941

29 June 1961

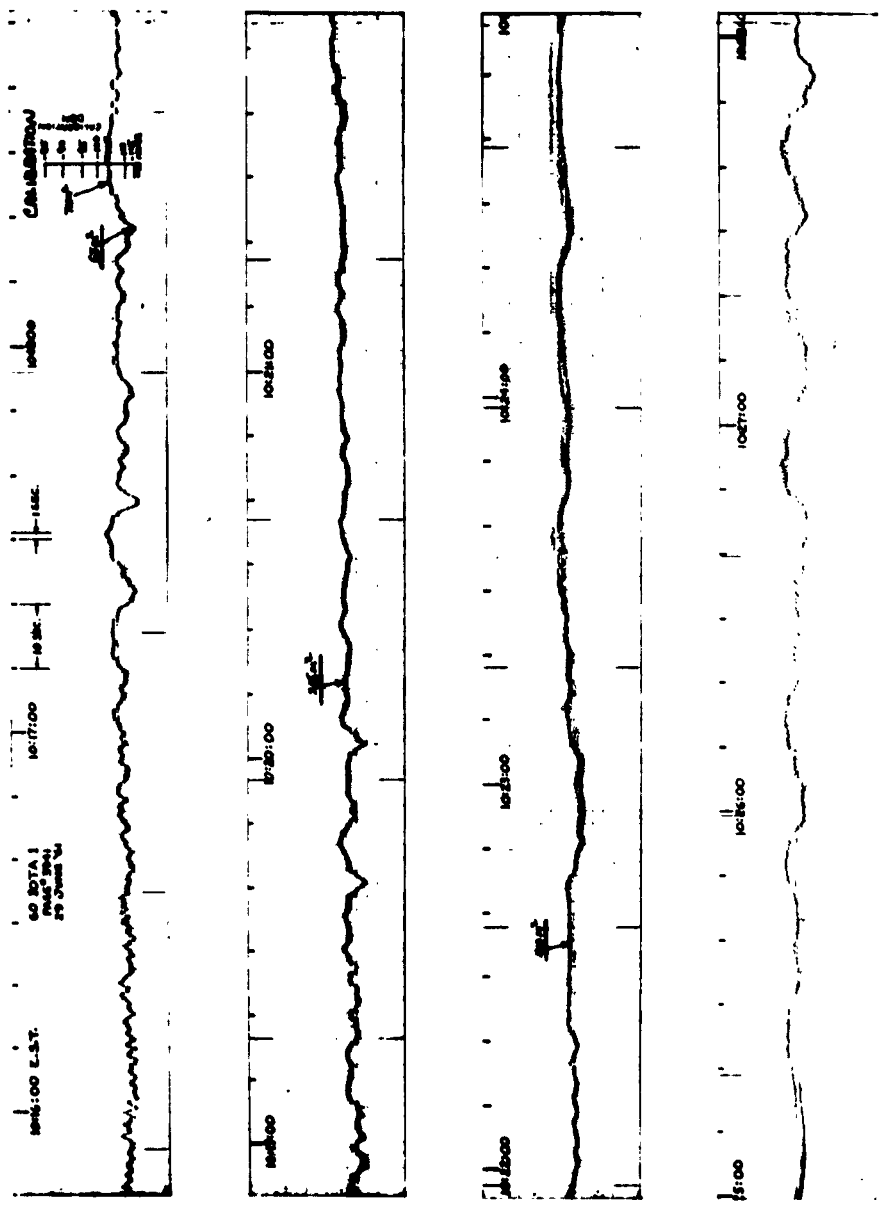


FIG. 12 PLATE 1

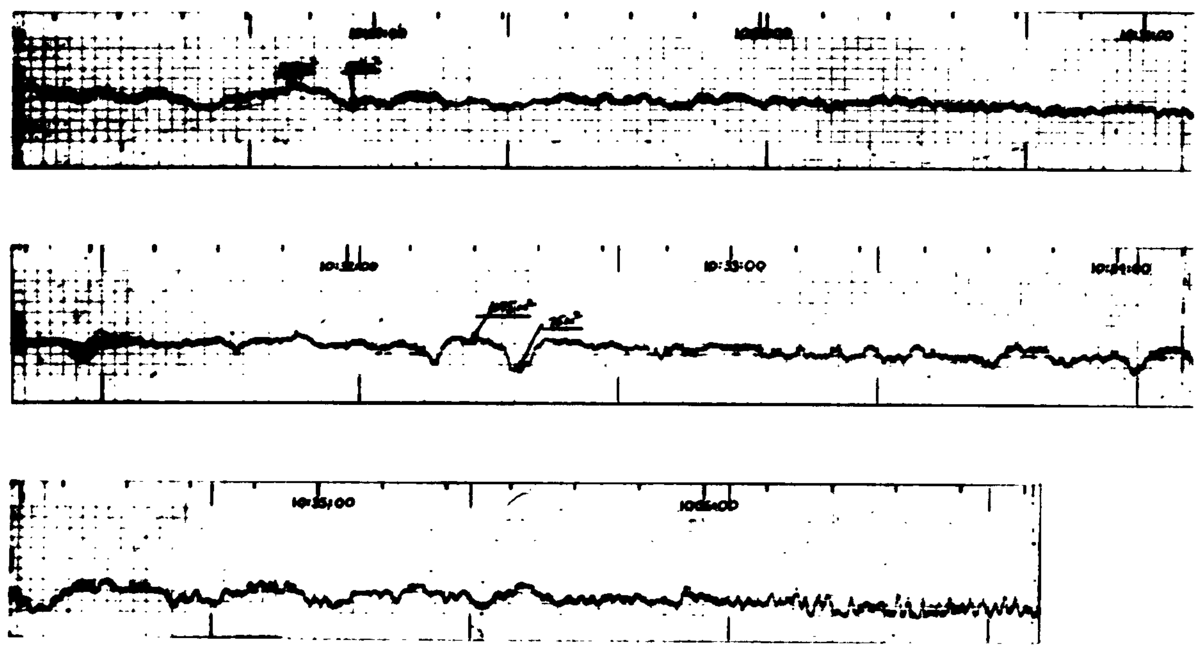


FIG. 12 PLATE 2

ECHO I AMPLITUDE

Revolution 4268

25 July 1961

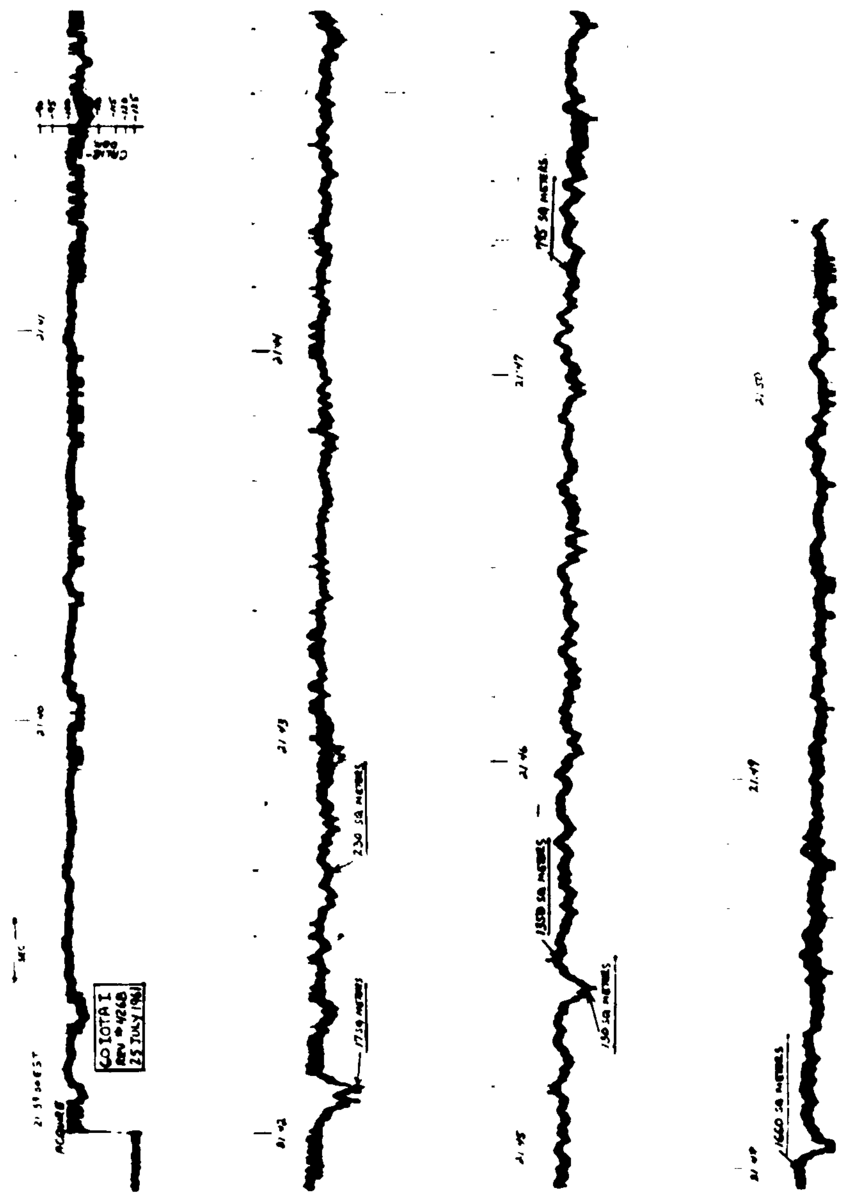


FIG. 13

ECHO I AMPLITUDE

Revolution 5159

6 October 1961

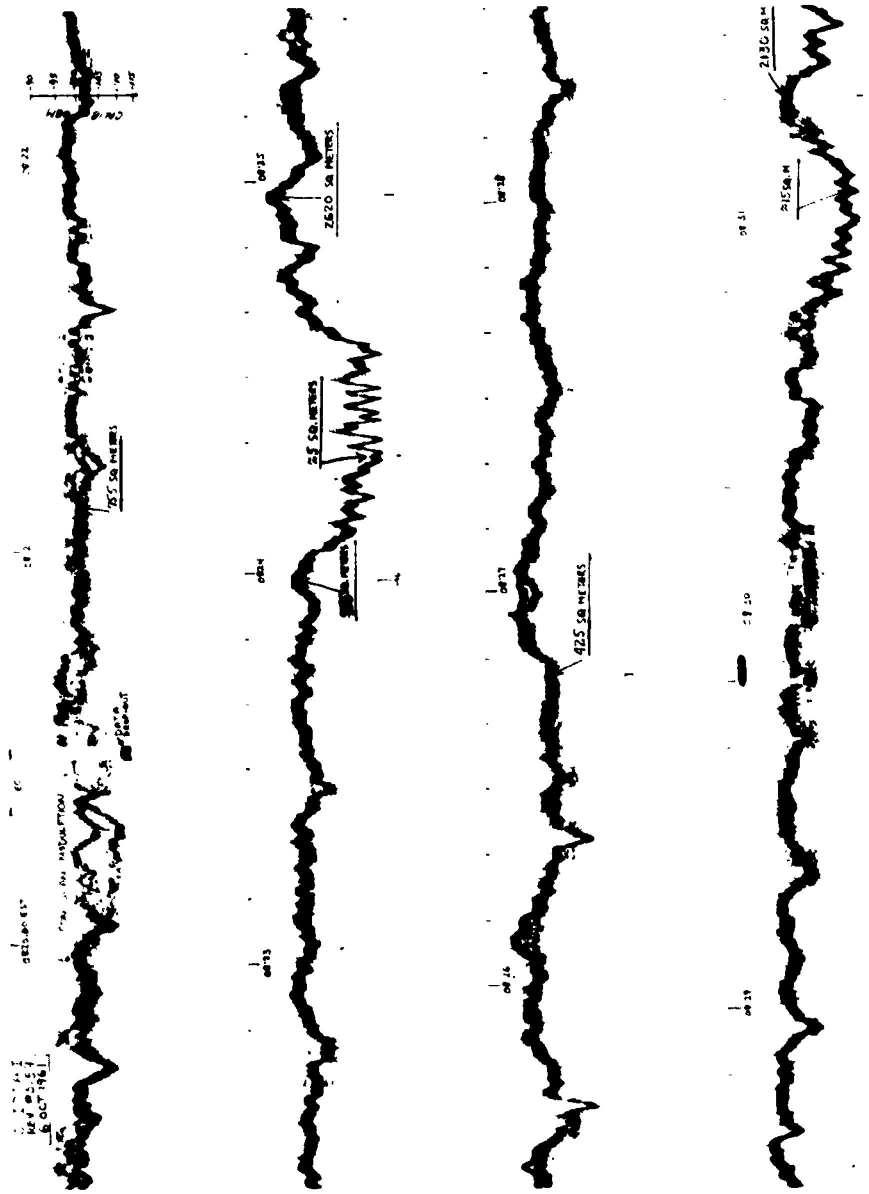


FIG. 14 PLATE 1

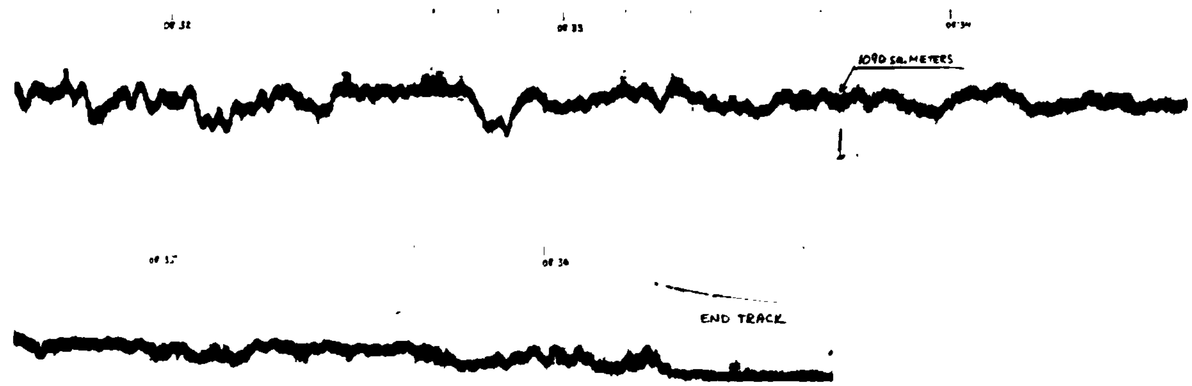


FIG. 14 PLATE 2

APPENDIX

Millstone-PARL UHF Communications Experiment*

During revolution 12 (13 August 1960) of the Echo I satellite, a communications experiment was carried out at 440 Mcs between the Millstone Hill Radar and the Prince Albert Radar Laboratory (PARL), Saskatchewan, Canada.

A pre-taped voice message was transmitted from Millstone via the satellite to PARL for a duration of some ten minutes using narrow-band FM. During the first portion of the pass, the Millstone dish was manually trained using predicted position data from Space Track as corrected by Millstone tracking data gathered on revolution 11. The last portion of the track was effected with an optical antenna director controlling the dish. PARL first acquired the target with its radar at 448 Mcs, and then automatically tracked on the Millstone communication signal.

During revolution 11, and earlier tracks, it was ascertained that the balloon had maintained its spherical shape to a very high degree and would be a good passive reflector for the experiment.

The quality of the received signal at PARL was good and possessed the expected signal-to-noise ratio (approximately 16 db under ideal conditions). The chronological sequence of events and signal strengths logged for this experiment are as shown on the following page.

* Data provided by D. R. Hansen, PARL.

Time Universal 13 Aug 60	Event (PARL)	Signal Strength: Received at PARL	Signal Strength: Calculated Ideal
09:04:29	Target first detected by radar.		
09:11:59	Millstone tone detected. Radar tracking continues (target range from PARL = 1100 n.m.).		
09:12:29	Track on Millstone signal.		
		Varies -127 to -124 dbm.	-123 dbm.
09:13:19	Voice transmission begins and is recorded. Apparent signal increase of 4 db when voice transmission begins.		
		Varies -130 to -120 dbm.	-118.5 to -121 dbm.
09:18:26	Conical scan stopped. An attempt to track signal manually is unsuccessful.		
09:19:45	Conical scan tracking resumed.		
09:20:05	(Millstone begins tracking with optical director.)		
		Varies -124 dbm to in excess of -118 dbm.	-118.5 dbm.
09:22:36			
09:24:20			
		Varies -127 to -124 dbm.	-119.5 to -122 dbm.
09:26:24			
09:28:10	Lose signal.		

PARAMETERS - PARL

Coordinates	53° 13' N, 106° W
Ground range from Millstone Radar	1512 nautical miles
Antenna* gain	35 db (while tracking)
Antenna beamwidth	2.1 degrees
Type tracker	conical scan (7.5 cps rate)
Receiver noise figure	5 db (approximately)
Receiver bandwidth	3 kcs
Receiver polarization	left circular

PARAMETERS - MILLSTONE

Coordinates	42° 37' N, 71° 29' W
Transmitted power	35 kw
Transmitted signal	CW FM 1 kc deviation
Transmitted polarization	right circular (out dish)
Antenna gain	37 db
Antenna beamwidth	2.1 degrees
Frequency	440 Mcs

* Millstone-type antenna